INSTITUTION

OF

MECHANICAL ENGINEERS.

PROCEEDINGS.

1871.

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1871.

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Institution of Mechanical Engineers,

81 *Newhall Street, Birmingham.*

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

1871.

MEMBERS.

1861\. Abel, Charles Denton, 20 Southampton Buildings, London, W.C.

1848\. Adams, William Alexander, Walford Manor, near Shrewsbury.

1859\. Adamson, Daniel, Newton Moor Iron Works, Hyde, near Manchester.

1871\. Adamson, Joseph, Messrs. Daniel Adamson and Co.'s Works, Newton Moor Iron Works, Hyde, near Manchester.

1861\. Addenbrooke, George, Messrs. Addenbrookes Smith and Pidcock, Rough Hay Furnaces, Darlaston, near Wednesbury.

1851\. Addison, John, 6 Delahay Street, Westminster, S.W.

1858\. Albaret, Auguste, Engine Works, Liancourt-Rantigny, Oise, France.

1870\. Alexander, Alfred, Corinium Iron Works, Cirencester.

1847\. Allan, Alexander, Bridge Street, Worcester.

1865\. Allen, William Daniel, Bessemer Steel Works, Sheffield.

1870\. Alley, John, Locomotive Superintendent, Moscow and Razan Railway, Moscow, Russia.

1865\. Alleyne, Sir John Gay Newton, Bart., Butterley Iron Works, Alfreton.

1871\. Allport, Howard Aston, Resident Engineer, Bedford and Northampton Railway ; Midland Railway, Derby.

1861\. Amos, Charles Edwards, 5 Cedars Road, Clapham Common, London, S.W.

1867\. Amos, James Chapman, Messrs. Easton Amos and Sons, Grove Works, Southwark Street, London, S.E.

1856\. Anderson, John, Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich, S.E.

1856\. Anderson, William, Messrs. Eastons and Anderson, Erith Iron Works, Erith, London, S.E.

1862\. Angus, Robert, Locomotive Superintendent, North Staffordshire Railway, Stoke-upon-Trent.

1858\. Appleby, Charles Edward, Renishaw Colliery, near Chesterfield.

1867. Appleby, Charles James, Messrs. Appleby Brothers, Emerson Street, Southwark. London, S.E.

1859. Armitage, William James, Farnley Iron Works, Leeds.

1866. Armstrong, George, Great Western Railway, Locomotive Department, Stafford Road Works, Wolverhampton.

1863. Armstrong, John, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1857. Armstrong, Joseph, Locomotive Superintendent, Great Western Railway, Swindon.

1858. Armstrong, Sir William George, C.B., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.

1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1857. Ashbury, James Lloyd, 9 Sussex Place, Hyde Park Gardens, London, W.

1870. Atkinson, Charles Fanshawe, Messrs. Marriott and Atkinson, Fitzalan Steel Works, Sheffield.

1869. Austin, William Lawson, Messrs. Austin and Dodson, Cambria Steel and File Works, Sheffield.

1869. Aveling, Thomas, Messrs. Aveling and Porter, Rochester.

1865. Bagshawe, John J., Thames Steel Works, Sheffield.

1865. Bailey, John, Messrs. Courtney Stephens and Co., Blackhall Place Iron Works, Dublin.

1860. Bailey, Samuel, Mining Engineer, The Pleck, near Walsall.

1866. Baines, William, London Works, Soho, near Birmingham.

1866. Baker, Samuel, 22 Oil Street, Liverpool.

1865. Baldwin, Martin, Bovereux Iron Works, Bilston.

1870. Barber, Thomas, Jun., Mining Engineer, High Park Collieries, Eastwood, Nottinghamshire.

1870. Barclay, Arthur, care of Hugh Barclay, Westfield, Surbiton, Kingston-on-Thames.

1860. Barclay, John, Bowling Iron Works, near Bradford, Yorkshire.

1860. Barker, Paul, Old Park Iron Works, Wednesbury.

1866. Barnard, Clement, 11 Billiter Square, London, E.C.

1862. Barrow, Joseph, Whalley Chambers, 88 King Street, Manchester.

1867. Barrows, Thomas Welch, Portable Engine Works, Banbury.

1871. Barry, John Wolfe, 18 Duke Street, Westminster, S.W.

1862. Barton, Edward, Carnforth Hæmatite Iron Works, Carnforth, near Lancaster.

1860. Batho, William Fothergill, Melrose House, Erdington, Birmingham.

1865. Beardshaw, Charles C., Baltic Steel Works, Sheffield.

1848. Beattie, Joseph Hamilton, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.

1869. Beattie, William George, London and South Western Railway, Locomotive Department, Nine Elms, London. S.W.

1859. Beck, Edward, Messrs. Neild and Co., Dallam Iron Works, Warrington. (*Life Member.*)

1864. Beckton, James George, Whitby, Yorkshire.

1865. Bell, Charles. Thorncliffe Iron Works, near Sheffield.

1858. Bell, Isaac Lowthian, Clarence Felling and Wylam Iron Works, Newcastle-on-Tyne ; and The Hall, Washington, County Durham.

1857. Bellhouse, Edward Taylor, Eagle Foundry, Hunt Street, Oxford Street, Manchester.

1868. Belliss, George Edward, Steam Engine and Boiler Works, 13 Broad Street, Birmingham.

1854. Bennett, Peter Duckworth, Spon Lane Iron Foundry, Westbromwich.

1865. Benson, George Henry, Stalybridge.

1867. Berkley, George, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1861. Bessemer, Henry, 4 Queen Street Place, New Cannon Street, London, E.C.

1866. Bevis, Restel Ratsey, Birkenhead Iron Works, Birkenhead.

1870. Bewlay, Hubert, Birmingham Heath Boiler Works, Spring Hill, Birmingham.

1847. Beyer, Charles F., Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.

1863. Birckel, John James, care of Colonel Dorn, Comité d'Artillerie, St. Thomas d'Aquin, Paris : (or care of J. C. Wagstaff, 755 Hyde Road, Gorton, Manchester.)

1866. Birkbeck, John Addison, Sheepbridge Iron Works, Chesterfield.

1847. Birley, Henry, Haigh Foundry, near Wigan.

1865. Bladen, Charles, Blochairn Iron Works, Glasgow.

1870. Blair, John, Chief Locomotive Superintendent, Danish Government Railways, Aarhuus, Denmark.

1862. Blake, Henry Wollaston, Messrs. James Watt and Co., 18 London Street, London, E. C.

1867. Bleckly, John James, Bewsey Iron Works, Warrington.

1869. Bloomer, Benjamin Giles, Pelsall Coal and Iron Works, near Walsall.

1862. Blyth, Alfred, Steam Engine Works, Fore Street, Limehouse, London, E.

1863. Boeddinghaus, Julius, Messrs. Heinrich Boeddinghaus and Sons, Elberfeld, Prussia.

1869. Borrie, John, Messrs. Bolckow Vaughan and Co.'s Works, Cleveland Iron Works, Middlesbrough.

1862. Bouch, Thomas, 78 George Street, Edinburgh.

1858. Bouch, William, Shildon Engine Works, Darlington.

1870. Bower, Anthony, Messrs. Forrester and Co., Vauxhall Foundry, Liverpool.

1858. Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester. (*Life Member.*)

1862. Boyd, Nelson, 5 Mitre Court Chambers, Mitre Court, Fleet Street, London, E.C.

1869. Boyd, William, Messrs. Thompson and Boyd, Spring Gardens Engine Works, Newcastle-on-Tyne.

1854. Bragge, William, Sir John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1854. Bramwell, Frederick Joseph, 37 Great George Street, Westminster, S.W.

1868. Breeden, Joseph, 156 Cheapside, Birmingham.

1848. Broad, Robert, Horseley Iron Works, near Tipton.

1865. Brock, Walter, Engine Works, Dumbarton.

1852. Brogden, Henry, Sale, near Manchester. (*Life Member.*)

1866. Brown, Andrew Betts, 80 Cannon Street, London, E.C.

1865. Brown, George, Rotherham Iron Works, Rotherham.

1863. Brown, Henry, Messrs. Allen Everitt and Sons' Works, Kingston Metal Works, Adderley Street, Birmingham.

1847. Brown, James, Jun., Messrs. James Watt and Co., Soho Foundry, near Birmingham.

1850. Brown, Sir John, Atlas Steel and Iron Works, Sheffield.

1853. Brown, Ralph, Patent Shaft Works, Wednesbury.

1869. Browne, Benjamin Chapman, Messrs. Hawthorn and Co., Newcastle-on-Tyne.

1869. Browne, Walter Raleigh, Messrs. John Knight and Co., Cookley Iron Works, near Kidderminster.

1867. Bruce, William Duff, Vice-Chairman, Port Commission, Calcutta, India.

1870. Brunlees, James, 5 Victoria Street, Westminster, S.W.

1865. Bryant, Frederick William, Albert Bridge Works, 33 Cheyne Walk, Chelsea, London, S.W.

1866. Bryham, William, Rose Bridge and Douglas Bank Collieries, near Wigan.

1870. Burgh, Nicholas Proctor, 78 Waterloo Bridge, London, S.

1858. Burn, Henry, Atlas Iron Works, Litchurch, Derby.

1871. Burrows, James, Wigan.

1870. Bury, William, Messrs. Forrester and Co.'s Works, Vauxhall Foundry, Liverpool.

1856. Butler, Ambrose Edmund, Kirkstall Forge, near Leeds.

1859. Butler, John, Stanningley Iron Works, near Leeds.

1859. Butler, John Octavius, Kirkstall Forge, near Leeds.

1871. Cabry, Charles, District Resident Engineer, North Eastern Railway, York.

1857. Cabry, Joseph, Resident Engineer, Blyth and Tyne Railway, Newcastle-on-Tyne.

1847. Cabry, Thomas, North Eastern Railway, York.

1847. Cammell, Charles, Cyclops Steel and Iron Works, Sheffield.

1867. Campbell, Daniel, 10 John Street, Adelphi, London, W.C.

1864. Campbell, David, care of A. F. Morris, Nautical Assistant, Harbour Department, Mazagon, Bombay, India.

1864. Campbell, James, Staveley Coal and Iron Works, Staveley, near Chesterfield.

1869. Campbell, James, Hunslet Engine Works, Leeds.

1860. Cannell, Fleetwood James, Sir John Brown and Co.'s Works, Atlas Steel and Iron Works, Sheffield.

1860. Carbutt, Edward Hamer, Messrs. Thwaites and Carbutt, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.

1865. Carlton, Samuel, Great Western Railway, Locomotive Department, Swindon.

1869. Carpmael, Frederick, 77 Manor Road, Lewisham Road, London, S.E.

1866. Carpmael, William, 24 Southampton Buildings, London, W.C.

1868. Carrington, Thomas, Jun., Mining Engineer, Kiveton Park Colliery, near Sheffield.

1864. Carrington, William Thomas, Engineer, Jersey Water Works, Halkett House, King Street, St. Helier's, Jersey.

1858. Carson, James Irving, Locomotive Superintendent, West Hartlepool Harbour and Railway, Stockton-on-Tees.

1870. Carver, James, Lace-Bobbin and Carriage Works, Butcher Street, Nottingham.

1869. Caspersen, Hans William, Engineer, Danish Government Railway Service; 27 Ashfield Terrace West, Newcastle-on-Tyne.

1869. Chadwick, John, Junction Foundry, Watson Street, Peter Street, Manchester.

1871. Chamberlain, Walter, Messrs. Nettlefold's Screw Works, Smethwick, near Birmingham.

1866. Chapman, Henry, 41 Boulevard Malesherbes, Paris: (or care of George Edward Chapman, 41 Parliament Street, Westminster, S.W.)

1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton.

1869. Checkley, Thomas, Mining Engineer, Lichfield Street, Walsall.

1857. Chrimes, Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1869. Clapham, Robert Calvert, Walker Alkali Works, Newcastle-on-Tyne.

1866. Claridge, Thomas, Messrs. Claridge and North, Phœnix Foundry, near Bilston.

1871. Clark, Christopher Fisher, Mining Engineer, Garswood, near Newton-le-Willows.
1859. Clark, George, Monkwearmouth Engine Works, Sunderland.
1867. Clark, George, Jun., Monkwearmouth Engine Works, Sunderland.
1862. Clark, James, Wellington Foundry, Leeds.
1869. Clark, Thomas, Ironfoundry, Low Elswick, Newcastle-on-Tyne.
1867. Clark, William, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1869. Clark, William, Mining Engineer, Teversall Collieries, near Mansfield.
1865. Clarke, John, Messrs. Hudswell Clarke and Rodgers, Railway Foundry, Jack Lane, Leeds.
1869. Clarke, William, Messrs. Clarke Watson and Gurney, Victoria Works, Gateshead.
1859. Clay, William, Birkenhead Forge Iron Works, Beaufort Road, Birkenhead.
1870. Clayton, Nathaniel, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.
1863. Clayton, Robert, Soho Foundry, Preston.
1871. Cleminson, James, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1869. Clerk, Francis North, Mitre Galvanising Works, Wolverhampton.
1866. Cleworth, Charles, District Locomotive Superintendent, East Indian Railway, Jumalpore, India ; and 24 Pembroke Grove, Plymouth Grove, Manchester.
1867. Cliff, Joseph, Union Foundry, Bradford, Yorkshire.
1847. Clift, John Edward, Redditch Gas Works, Redditch.
1858. Cochrane, Charles, Woodside Iron Works, near Dudley ; and The Grange, Stourbridge.
1860. Cochrane, Henry, Ormesby Iron Works, Middlesbrough.
1854. Cochrane, John, 3 Hyde Park Gate, London, W.
1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.
1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne.
1867. Cockey, Francis Christopher, Selwood Iron Works, Frome.
1864. Coddington, William, Ordnance Cotton Mill, Blackburn.
1847. Coke, Richard George, Mining Engineer, Chesterfield.
1867. Coke, William Langton, 11 Great Queen Street, Westminster, S.W.
1853. Cooper, Samuel Thomas, Leeds Iron Works, Leeds.
1848. Corry, Edward, 8 New Broad Street, London, E.C.
1868. Coulson, William, Mining Engineer, Shamrock House, Durham.
1864. Cowans, John, Messrs. Cowans Sheldon and Co., St. Nicholas Iron and Engine Works, Carlisle.
1870. Cowen, George Roberts, Beck Foundry, Brook Street, Nottingham.
1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.

1847. Crampton, Thomas Russell, 12 Great George Street, Westminster, S.W.
1871. Craven, Joseph, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.
1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.
1865. Cross, James, Ditton Lodge, Warrington.
1869. Crossley, Louis J., Dean Clough Carpet Mills, Halifax.
1871. Crossley, William, Furness Iron and Steel Works, Askam, near Dalton-in-Furness, Lancashire.
1863. Crow, George, Messrs. R. Stephenson and Co.'s Works. Newcastle-on-Tyne.
1864. Crowe, Edward, Messrs. Hopkins Gilkes and Co.'s Works, Tees Engine Works, Middlesbrough.

1864. Daglish, George Heaton, St. Helen's Foundry, St. Helen's.
1869. Daglish, John, Mining Engineer, Tynemouth, near North Shields.
1866. Daniel, Edward Freer, Shrewsbury.
1866. Daniel, William, 11 Blenheim Square, Leeds.
1865. Darby, Abraham, Ebbw Vale Iron Works, near Beaufort, Monmouthshire.
1864. Darby, Charles E., Brymbo Iron Works, near Wrexham.
1865. Davidson, James, Royal Arsenal, Laboratory Department, Woolwich, S.E.
1868. Davis, Henry Wheeler, Resident Engineer, Great Eastern Railway, Stratford, London, E.
1863. Davy, Alfred, Park Iron Works, Sheffield.
1849. Dawes, George, Milton and Elsecar Iron Works. near Barnsley.
1861. Dawson, Benjamin, 9 St. George's Square, Sunderland.
1869. Day, St. John Vincent, 166 Buchanan Street, Glasgow.
1868. Dean, William, Great Western Railway, Locomotive Department, Swindon.
1866. Death, Ephraim, Albert Works, Leicester.
1857. De Bergue, Charles, 10 Strand, London, W.C.; and Strangeways Iron Works, Manchester.
1858. Dees, James, Whitehaven.
1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
1868. Derham, John J., Brookside, near Blackburn.
1865. Dircks, Henry, 48 Charing Cross, London, S.W. (*Life Member.*)
1865. Dobson, Benjamin, Messrs. Dobson and Barlow, Kay Street Works, Bolton.
1868. Dodman, Alfred, St. James's Works, Lynn.
1865. Douglas, Charles P., Consett Iron Works, near Blackhill, County Durham.
1857. Douglas, George K., Messrs. R. Stephenson and Co., Newcastle-on-Tyne.
1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Iron and Engine Works, Carlisle.
1866. Downey, Alfred C., Messrs. Cochrane and Co.'s Works, Ormesby Iron Works, Middlesbrough.
1847. Dübs, Henry, Glasgow Locomotive Works, Glasgow.

1870. Dunlop, James Wilkie, 22 Leadenhall Street, London, E.C.

1857. Dunlop, John Macmillan, Holehird, Windermere.

1864. Dunn, Thomas Edward, Kurhurballee Collieries, Chord Line East Indian Railway, viâ Muddapur Junction, India: (or care of R. Dunn, Howick, Bilton, Northumberland.)

1860. Dyson, George, Saltburn-by-the-Sea, Yorkshire.

1865. Dyson, Robert, Phœnix Wheel Tyre and Axle Works, Rotherham.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.

1859. Eassie, Peter Boyd, Messrs. William Eassie and Co., Railway Saw Mills, Gloucester.

1858. Easton, Edward, Messrs. Easton Amos and Sons, Grove Works, Southwark Street, London, S.E.

1867. Easton, James, Mining Engineer, Nest House, Gateshead.

1856. Eastwood, James, Railway Iron Works, Derby.

1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1871. Edwards, Edgar James, Butterley Iron Works, Alfreton.

1866. Elce, John, Phœnix Iron Works, Jersey Street, Manchester.

1859. Elliot, George, M.P., Houghton-le-Spring, near Fence Houses.

1869. Elliott, Henry Worton, Metal Sheathing Works, Coleshill Street, Birmingham.

1870. Elsdon, Robert, Brockham Green, near Reigate.

1869. Elwell, Alfred, Edge Tool Works, Wood Green, Wednesbury.

1860. Elwell, Thomas, Messrs. Varrall Elwell and Poulot, 9 Avenue Trudaine, Paris.

1857. Evans, John Campbell, 28 Grosvenor Road, Highbury New Park, London, N.

1864. Everitt, William Edward, Kingston Metal Works, Adderley Street, Birmingham.

1865. Evers, Frank, Cradley Iron Works, near Stourbridge.

1869. Eyth, Max, Messrs. John Fowler and Co.'s Works, Steam Plough and Locomotive Works, Leeds.

1869. Faija, Henry, 9 Southampton Street, Fitzroy Square, London, W.

1868. Fairbairn, Sir Andrew, Wellington Foundry, Leeds.

1869. Fairless, John, Forth Banks Engine Works, Newcastle-on-Tyne.

1857. Fairlie, Robert Francis, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1867. Fardon, Thomas, Linslade Iron Works, Leighton Buzzard.

1865. Faviell, Samuel Clough, Messrs. Taylor Brothers and Co.'s Works, Clarence Iron Works, Leeds.
1866. Fenby, Joseph Beverley, 19 Albert Street, Smallheath, Birmingham.
1870. Ferguson, Henry Tanner, District Locomotive Superintendent, South Devon, Cornwall, and West Cornwall Railways, Carn Brea Works, Redruth.
1854. Fernie, John, Ventnor, Isle of Wight.
1866. Fiddes, Walter, Engineer, Bristol United Gas Works, Bristol.
1867. Field, Edward, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.
1861. Field, Joshua, 110 Westminster Bridge Road, Lambeth, London, S.E.
1865. Filliter, Edward, Resident Engineer, Leeds Water Works, 16 East Parade, Leeds.
1868. Firth, Arthur, Leeds Iron Works, Leeds.
1868. Firth, Samuel, 14 Springfield Mount, Leeds.
1871. Fisher Benjamin Samuel, Locomotive Superintendent, Taff Vale Railway, Cardiff Docks, Cardiff.
1864. Fleet, Thomas, Crown Boiler Works, Westbromwich.
1847. Fletcher, Edward, Locomotive Superintendent, North Eastern Railway, Gateshead.
1858. Fletcher, Henry Allason, Lowca Engine Works, Whitehaven. (*Life Member.*)
1857. Fletcher, James, Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.
1866. Fletcher, James, Jun., Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.
1867. Fletcher, Lavington Evans, Chief Engineer, Association for the Prevention of Steam Boiler Explosions, 41 Corporation Street, Manchester.
1859. Fogg, Robert, 17 Park Street, Westminster, S.W.
1871. Forrest, William John, Assistant Engineer, Intercolonial Railway, Ottawa, Canada.
1861. Forster, Edward, Spon Lane Glass Works, near Birmingham.
1869. Forster, George Baker, Backworth, Newcastle-on-Tyne.
1868. Forster, John, Messrs. Westray and Forster, Abbey Road, Barrow-in-Furness, Lancashire.
1849. Forsyth, John C., North Staffordshire Railway, Stoke-upon-Trent.
1861. Foster, Sampson Lloyd, Old Park Hall, Walsall.
1866. Fowler, George, Mining Engineer, 56 Clarendon Street, Nottingham.
1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.
1866. Fox, Charles Douglas, 6 Delahay Street, Westminster, S.W.
1859. Fraser, John, 18 York Place, Leeds.

1866. Fraser, John Simpson, Peabody Villa, Louisiana Road, Peckham, London, S.E.

1870. Freeman, George Frederick, Broughton Copper Works, Broughton Road, Manchester.

1856. Freeman, Joseph, 98 Cannon Street, London, E.C.

1864. Frost, Thomas, Wadsley Bridge Iron and Steel Works, near Sheffield.

1852. Froude, William, Chelston Cross, Torquay.

1866. Fry, Albert, Bristol Wagon Works, Temple Gate, Bristol.

1866. Galloway, Charles John, Knott Mill Iron Works, Manchester.

1862. Galton, Capt. Douglas, R.E., War Office, Pall Mall, London, S.W.

1847. Garland, William S., Messrs. James Watt and Co., Soho Foundry, near Birmingham.

1870. Garstang, James H., Bank Top Foundry, Blackburn.

1867. Gauntlett, William Henry, 9 Grange Road, Middlesbrough.

1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham.

1848. Gibbons, Benjamin, The Leasowes, near Birmingham.

1870. Gibson, John, Engineer, Ryhope Colliery, near Sunderland.

1856. Gilkes, Edgar, Messrs. Hopkins Gilkes and Co., Tees Engine Works, Middlesbrough.

1869. Gillies, Malcolm, Great Eastern Railway, Locomotive Department, Stratford, London, E.

1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.

1862. Godfrey, Samuel, Messrs. Bolckow Vaughan and Co.'s Iron Works, Middlesbrough.

1867. Gooch, William Frederick, Vulcan Foundry, Warrington.

1869. Goodeve, Thomas Minchin, Goldsmith Buildings, Temple, London, E.C.

1865. Göransson, Göran Fredrick, Steel Works, Gefle and Hägbo, Sweden.

1869. Grainger, James Nixon, Public Works Department, Chepauk, Madras, India.

1865. Gray, John McFarlane, Board of Trade Steam Ship Surveyor, 2 Deane Street, Cork.

1870. Gray, Matthew, 100 Cannon Street, London, E.C.; and Silvertown Telegraph Works, North Woolwich, E.

1870. Greaves, James Henry, 3 Great George Street, Westminster, S.W.

1861. Green, Edward, Jun., Phœnix Works, Wakefield.

1871. Greener, John Henry, 84 Lombard Street, London, E.C.

1858. Greenwood, Thomas, Albion Works, Armley Road, Leeds.

1865. Greig, David, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1866. Grice, Edwin James, Stour Valley Works, Spon Lane, Westbromwich.

1860. Grice, Frederic Groom, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1868. Grierson, Henry Houldsworth, Messrs. Ormerod Grierson and Co., St. George's Iron Works, Hulme, Manchester.

1871. Grover, Lieut. George Edward, R.E., International Exhibition, South Kensington, London, W.

1870. Guilford, Francis Leaver, Messrs. Cowen and Co., Beck Foundry, Brook Street, Nottingham.

1866. Gurden, Charles Frederick, Superintendent Engineer, Brazil and River Plate Steam Boat Co., 43 Canning Street, Birkenhead.

1870. Gwynne, James Eglinton Anderson, Essex Street Works, Strand, London, W.C. (*Life Member.*)

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.

1863. Hackney, William, Landore Steel Works, Swansea.

1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.

1863. Hall, Joseph, Gratz Iron Works, Gratz, Styria, Austria.

1871. Hall, William Silver, Engineer, Babbington Collieries, Cinder Hill, Nottingham.

1871. Halpin, Druitt, 24 Great George Street, Westminster, S.W.

1870. Hamand, Arthur Samuel, Stephenson Chambers, New Street, Birmingham.

1869. Hambling, Thomas Crump, 7 Westminster Chambers, Victoria Street, Westminster, S.W.

1860. Hamilton, Gilbert, Messrs. James Watt and Co., Soho Foundry, near Birmingham.

1870. Hannah, Joseph Edward, Stockton and Darlington Railway, Darlington.

1870. Harding, George Edward, 176 Broadway, New York, United States.

1858. Harding, John, Beeston Manor Iron Works, Leeds.

1869. Harfield, William Horatio, 28 Cornhill, London, E.C.

1859. Harman, Henry William, Canal Street Works, Manchester.

1856. Harrison, George, Canada Works, Birkenhead.

1871. Harrison, Joseph Edward, Messrs. Cochrane and Co.'s Works, Woodside Iron Works, near Dudley.

1858. Harrison, Thomas Elliot, 1 Westminster Chambers, Victoria Street, Westminster, S.W.

1865. Harrison, William, Bank Foundry, Blackburn.

1865. Harrison, William Arthur, Cambridge Street Works, Manchester.

1871. Hartness, John, Lloyds' Inspector, Wear Chain and Anchor Testing Works, Sunderland.

1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.

1857. Haughton, S. Wilfred, Greenbank, Carlow, Ireland. (*Life Member.*)

1861. Hawkins, William Bailey, 2 Suffolk Lane, Cannon Street, London, E.C.
1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.
1856. Hawksley, Thomas, 30 Great George Street, Westminster, S.W.
1848. Hawthorn, William. Messrs. Hawthorn and Co., Newcastle-on-Tyne.
1862. Haynes, Thomas John, Calpe Foundry, North Front, Gibraltar.
1869. Head. Jeremiah, Messrs. Fox Head and Co., Newport Rolling Mills, Middlesbrough.
1860. Head, John, Messrs. Ransomes Sims and Head, Orwell Works, Ipswich.
1853. Headly, James Ind, Eagle Foundry, Mill Road, Cambridge.
1857. Healey, Edward Charles, 163 Strand, London, W.C.
1864. Heathfield, Richard, Lion Galvanising Works, Birmingham Heath, Birmingham.
1868. Heaton, John, Langley Mill Steel and Iron Works, near Nottingham.
1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China.
1865. Hetherington, John Muir, Vulcan Works, Pollard Street, Manchester.
1866. Hetherington, Thomas Ridley, Vulcan Works, Pollard Street, Manchester.
1864. Hetherington, William Isaac, 5 Victoria Street, Westminster, S.W.
1865. Hewett, Edward Edwards, Messrs. Vickers Sons and Co.'s Works, River Don Works, Sheffield.
1871. Hick, John, M.P., Hill Top, Sharples, near Bolton.
1866. Hickman, George Haden, Groveland Iron Works, Dudley Port, Tipton.
1864. Hide, Thomas C., Messrs. Hide and Thompson, 4 Cullum Street, Fenchurch Street, London, E.C.
1870. Higson, John, Mining Engineer, 98 Cross Street, Manchester.
1871. Hill, Alfred C., Middlesbrough.
1867. Hill, Henry Walker, 51 Hampden Street, Nottingham.
1869. Hind. Henry, Central Works, Queen's Road, Nottingham.
1870. Hodges, Petronius, Yorkshire Steel and Iron Works, Penistone, near Sheffield.
1866. Hodgson, Charles, 21 Gresham Street, Old Jewry, London, E.C.
1858. Hodgson. Robert, North Eastern Railway, Newcastle-on-Tyne.
1852. Holcroft, James, Norton, near Stourbridge.
1866. Holcroft, Thomas, Bilston Foundry, Bilston.
1871. Holiday, Joseph, Union Foundry, Bradford, Yorkshire.
1865. Holliday, John, Messrs. Bethell's Creosote Works, Westbromwich.
1863. Holt, Francis, Messrs. Hawthorn's Engine Works, Newcastle-on-Tyne.
1867. Holt, William Lyster, 7 Great Winchester Street Buildings, London, E.C.
1867. Homer, Charles James, Mining Engineer, Chatterley Ironstone Works, Tunstall, near Stoke-upon-Trent.
1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.
1860. Hopkins, James Innes, The Poplars, Kingston-on-Thames.

1866. Hopkins, John Satchell, Tinplate Works, Granville Street, Birmingham.

1856. Hopkinson, John, Messrs. Wren and Hopkinson, London Road Iron Works, Manchester.

1867. Hopper, William, Machine Works, Moscow, Russia: (or care of Thomas Hopper, 46 Queen Street, Edinburgh.)

1868. Horsley, Thomas, Kirkby Old Hall, Pinxton, Alfreton.

1858. Horsley, William, Jun., Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.

1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.

1871. Horton, George, Messrs. Horton and Son, Steam Boiler Works, New Park Street, Southwark, London, S.E.

1851. Horton, Joshua, Ætna Works, Smethwick, near Birmingham.

1867. Horton, Thomas Ellwood, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.

1858. Hosking, John, Gateshead Iron Works, Gateshead.

1866. Houghton, John Campbell Arthur, Messrs. Cochrane and Co.'s Works, Woodside Iron Works, near Dudley.

1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1860. Howard, James, M.P., Messrs. J. and F. Howard, Britannia Iron Works, Bedford.

1867. Howard, Robert Luke, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1860. Howe, William, Clay Cross Coal and Iron Works, near Chesterfield.

1861. Howell, Joseph Bennett, Brook Steel Works, Brook Street, Sheffield.

1866. Hoyle, William Jennings, Elswick Works, Newcastle-on-Tyne.

1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.

1871. Hughes, Joseph, Messrs. Daniel Adamson and Co.'s Works, Newton Moor Iron Works, Hyde, near Manchester.

1864. Hulse, William Wilson, Whalley Chambers, 88 King Street, Manchester.

1870. Hunstone, William Henry, Springfield Iron Works, Salford, Manchester.

1859. Hunt, James P., Corngreaves Iron Works, near Birmingham.

1856. Hunt, Thomas, care of Thomas Edleston, London and North Western Railway, Crewe.

1864. Hutchinson, Edward, Messrs. Pease Hutchinson and Co., Skerne Iron Works, Darlington.

1863. Hutton, Walter Stuart, Messrs. Hutton and Macdonald, Prospect Works, Hunslet Lane, Leeds.

1865. Hyde, Lt.-Colonel Henry, R.E., Master of the Mint, Calcutta, India: (or care of Rev. H. M. C. Hyde, 184 The Grove, Camberwell, London, S.E.) (*Life Member.*)

1867. Inglis, William, Messrs. Hick Hargreaves and Co.'s Works, Soho Iron Works, Bolton.

1866. Ireland, William, care of Jonathan Ireland, Edward Street, Broughton Lane, Manchester.

1870. Jackson, John P., Mining Engineer, Clay Cross Coal and Iron Works, near Chesterfield.

1859. Jackson, Matthew Murray, Engineer-in-Chief, Imperial Danube Steam Navigation Works, Pesth, Austria.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester.

1860. Jackson, Samuel, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1866. Jaeger, Herrmann Frederic, Messrs. Beyer Peacock and Co.'s Works, Gorton Foundry, Manchester.

1858. Jaffrey, George William, Messrs. Tod and McGregor's Shipbuilding Works, Partick, Glasgow.

1856. James, Jabez, 40 Prince's Street, Commercial Road, Lambeth, London, S.E.

1868. James, John, Richmond Villa, Maindee, near Newport, Monmouthshire.

1870. Jamieson, John Lennox Kincaid, Messrs. John Elder and Co., Engineers and Shipbuilders, 12 Centre Street, Glasgow; and Govan.

1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.

1863. Jeffreys, Edward A., Low Moor Iron Works, near Bradford, Yorkshire.

1861. Jessop, Thomas, Park Steel Works, Sheffield.

1854. Jobson, John, Derwent Foundry, Derby.

1868. Jobson, Robert, Phœnix Works, Dudley.

1863. Johnson, Bryan, Messrs. Johnson and Ellington, Flookersbrook Foundry, Chester.

1847. Johnson, James, Belmont House, Starbeck, near Harrogate.

1861. Johnson, Samuel Waite, Locomotive Superintendent, Great Eastern Railway, Stratford, London, E.

1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.

1847. Jones, Edward, The Larches, Handsworth, near Birmingham.

1857. Jones, Hodgson, 67 Victoria Street, Westminster, S.W.

1857. Kay, James Clarkson, Phœnix Foundry, Bury, Lancashire.

1869. Keen, Arthur, Patent Nut and Bolt Works, Smethwick, near Birmingham.

1869. Keep, Alfred, Metal Sheathing Works, Coleshill Street, Birmingham.

1867. Kellett, John, 2 Newshams Buildings, King Street, Wigan.

1857. Kendall, William, Locomotive Superintendent, Blyth and Tyne Railway, Percy Main, near Newcastle-on-Tyne.

1863. Kennan, James, Agricultural Implement Works, 19 Fishamble Street, Dublin.

1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.

1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway; 45 Finsbury Circus, London, E.C.

1868. Kennedy, Thomas Stuart, Wellington Foundry, Leeds.

1866. Kershaw, John, 24 Duke Street, Westminster, S.W.

1867. Kimball, Frederick James, 35 South Third Street, Philadelphia, Pennsylvania, United States.

1870. Kinsey, Henry, Robin Hood Engine Works, Queen's Road, Nottingham.

1847. Kirtley, Matthew, Locomotive Superintendent, Midland Railway, Derby.

1864. Kirtley, William, Midland Railway, Locomotive Department, Derby.

1859. Kitson, Frederick William, Monkbridge Iron Works, Leeds.

1848. Kitson, James, Airedale Foundry, Leeds.

1859. Kitson, James, Jun., Monkbridge Iron Works, Leeds.

1868. Kitson, John Hawthorn, Airedale Foundry, Leeds.

1869. Koe, Stephen Lancelot, Bowling Iron Works, near Bradford, Yorkshire.

1869. Kohn, Ferdinand, 6 Robert Street, Adelphi, London, W.C.

1866. Lambert, William Blake, 3 Morden Road, Blackheath, London, S.E.

1867. Lancaster, Charles William, Gun Manufactory, 151 New Bond Street, London, W.

1863. Lancaster, John, M.P., Bilton Grange, Rugby.

1870. Lancaster, Joshua, Mostyn Coal and Iron Works, Holywell, North Wales.

1867. Lawrence, Henry, The Grange Iron Works, Durham.

1870. Layborn, Daniel, Messrs. Gladstone and Wyllie's Cotton Rice and Oil Factories, Rangoon, Burmah, India: (or care of Daniel Layborn, Sen., Beverley.)

1857. Laybourne, John, Isca Foundry, Newport, Monmouthshire.

1856. Laybourne, Richard, Rhymney Iron Works, Tredegar.

1860. Lea, Henry, 35 Paradise Street, Birmingham.

1868. Lea, John, Bowling Iron Works, near Bradford, Yorkshire.

1865. Ledger, Joseph, Iron Ore Office, Workington.

1862. Lee, J. C. Frank, 22 Great George Street, Westminster, S.W.

1871. Lee, William, Messrs. Lee Clerk and Robinson, Gospel Oak Iron Works, Tipton.

1863. Lees, Samuel, Jun., Park Bridge Iron Works, Ashton-under-Lyne.

1863. Leigh, Evan, Town Hall Buildings, Manchester.

1866. Leigh, Joseph D., Ellesmere Foundry, Patricroft, near Manchester.

1870. Leonard, Edward James, East India Chambers, 23 Leadenhall Street, London, E.C.

1858. Leslie, Andrew, Iron Shipbuilding Yard, Hebburn Quay, Gateshead.

1860. Lewis, Thomas William, Abercanaid House, Merthyr Tydvil.
1864. Lindsley, George, Great Western Railway, Locomotive Department, Swindon.
1856. Linn, Alexander Grainger, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1866. Little, George, Messrs. Platt Brothers and Co.'s Works, Hartford Iron Works, Oldham.
1867. Livesey, James, 9 Victoria Chambers, Victoria Street, Westminster. S.W.
1867. Lloyd. Charles, care of Edward J. Lloyd, 6 Victoria Grove, Fulham Road, London, S.W.
1863. Lloyd, Edward R., Albion Tube Works, Nile Street, Birmingham.
1871. Lloyd, Francis Henry, Old Park Iron Works, Wednesbury.
1854. Lloyd, George Braithwaite, Messrs. Lloyds, High Street, Birmingham. (*Life Member.*)
1862. Lloyd, John, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.
1866. Lloyd, Joseph Foster, 1 Temple Row West, Birmingham.
1847. Lloyd, Sampson, Old Park Iron Works, Wednesbury; and Wassell Grove, near Stourbridge.
1864. Lloyd, Sampson Zachary, Old Park Iron Works, Wednesbury.
1852. Lloyd, Samuel, The Farm, Sparkbrook, Birmingham.
1862. Lloyd, Wilson, Darlaston Green Iron and Steel Works, near Wednesbury.
1863. Loam, Matthew Hill, Engineer, Gas and Water Works, Nottingham.
1869. Lockhart, Humphrey Campbell, Birmingham Plate Glass Works, Smethwick, near Birmingham.
1856. Longridge, Robert Bewick, Chief Engineer, Steam Boiler Insurance Company, 67 King Street, Manchester.
1865. Longridge, William Smith, Alderwasley Iron Works, Ambergate, near Derby.
1866. Lord, Edward, Canal Street Works, Todmorden.
1861. Low, George, St. Peter's Iron Works, Ipswich.
1854. Lynde, James Gascoigne, Town Hall. Manchester.
1868. Lyndon, George Frederick, Minerva Works, Fazeley Street, Birmingham.

1869. Mabbutt, Thomas, Abingdon Gun Works, Shadwell Street, Birmingham.
1864. Macfarlane, Walter, Saracen Foundry, Washington Street, Glasgow.
1856. Mackay, John, Mount Hermon, Drogheda.
1864. Macnab, Archibald Francis, Japanese Government Service, Yokohama, Japan.
1865. MacNay, William, Shildon Engine Works, Darlington.
1865. Macnee, Daniel, Brinsworth Iron and Steel Works, Rotherham.
1867. Mallet, Robert, 7 Westminster Chambers, Victoria Street, Westminster, S.W.

1859. Manning, John, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.

1862. Mansell, Richard Christopher, South Eastern Railway, Carriage Department, Ashford.

1862. Mappin, Frederick Thorpe, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

1857. March, George, Union Foundry, Dewsbury Road, Leeds.

1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.

1871. Marsh, Henry William, Islip Iron Works, near Thrapston.

1865. Marshall, Francis Carr, Messrs. Hawthorn and Co., Newcastle-on-Tyne.

1862. Marshall, James, South Skelton Mines, Marske-by-the-Sea, Yorkshire.

1871. Marshall, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.

1859. Marshall, William Ebenezer, Sun Foundry, Dewsbury Road, Leeds.

1847. Marshall, William Prime, 81 Newhall Street, Birmingham.

1859. Marten, Edward Bindon, Engineer, Stourbridge Water Works, 56 Hagley Street, Stourbridge.

1853. Marten, Henry John, Parkfield Iron Works, near Wolverhampton.

1867. Martin, William, Messrs. W. Martin Fils et Cie., 43 Rue d'Elbeuf, Rouen, France.

1857. Martindale, Lt.-Colonel Ben Hay, C.B., R.E., Controller, Quebec, Canada.

1854. Martineau, Francis Edgar, Globe Works, Cliveland Street, Birmingham.

1864. Martley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W.

1857. Masselin, Armand, 14 Rue de Lancry, Paris.

1867. Mather, William, Messrs. Mather and Platt, Salford Iron Works, Manchester.

1853. Mathews, William, Park Field, Great Malvern.

1847. Matthews, William Anthony, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

1853. Maudslay, Henry, Bystock, near Exmouth. (*Life Member.*)

1864. Maudslay, Thomas Henry, 110 Westminster Bridge Road, Lambeth, London, S.E.

1869. Maughan, Thomas, Engineer, Cramlington Colliery, Cramlington, Northumberland.

1869. May, George, Mining Engineer, North Hetton and Pittington Collieries, Fence Houses.

1861. May, Robert Charles, 6 Great George Street, Westminster, S.W.

1857. May, Walter, Messrs. May and Mountain, Suffolk Works, Berkley Street, Birmingham.

1865. Maylor, John, 11 Commerce Chambers, Lord Street, Liverpool.

1859. Maylor, William. Calicut. Madras, India.
1847. McClean. John Robinson, M.P., 23 Great George Street, Westminster, S.W.
1865. McDonnell, Alexander, Locomotive Superintendent, Great Southern and Western Railway, Dublin.
1867. McEwen, James, Messrs. Firmstone and McEwen, Wordsley Foundry, Stourbridge.
1864. McEwen, Lawrence Thompson, Lombard House, George Yard, Lombard Street, London, E.C.
1868. McKay, Benjamin, Small Arms Factory, Small Heath, near Birmingham.
1863. Meek, Sturges, Resident Engineer, Lancashire and Yorkshire Railway, Manchester.
1858. Meik, Thomas, Engineer to the River Wear Commissioners, 28 Fawcett Street, Sunderland.
1857. Menelaus, William. Dowlais Iron Works, Merthyr Tydvil.
1866. Meredith, Alban, 18 Clement's Inn, Strand. London, W.C.
1867. Merryweather, Richard M., Fire Engine Works. 63 Long Acre, London, W.C.
1857. Metford, William Ellis, 26 Apsley Road, Redland, Bristol.
1862. Miers, Francis C., Stoneleigh Lodge, Grove Road, Clapham Park, London. S.W.
1864. Miers. John William. 74 Addison Road, Kensington, London, W.
1862. Millward. John, Curzon Chambers, 27 Paradise Street, Birmingham.
1856. Mitchell, Charles, Iron Shipbuilding Yard, Low Walker, Newcastle-on-Tyne.
1861. Mitchell, Joseph, Worsbrough Dale Colliery, near Barnsley.
1870. Moberley, Charles Henry, Messrs. Eastons and Anderson's Works, Erith Iron Works, Erith, London, S.E.
1859. Moor, William, Engineer, Hetton Colliery, Hetton, near Fence Houses.
1864. Moore, Sampson, North Foundry, Cotton Street, Clarence Dock, Liverpool.
1864. Morgan, Joshua Llewelyn, Wharfe House, Gilwern, near Abergavenny
1867. Morgans, Thomas, Messrs. James Fussell Sons and Co.'s Works, Mells Iron Works, near Frome.
1868. Morris, William, Waldridge Colliery, Chester-le-Street, near Fence Houses.
1865. Morton, Robert, Alliance Chambers, Borough, London, S.E.
1865. Mosse, James Robert, Public Works Office. Colombo, Ceylon.
1858. Mountain, Charles George, Messrs. May and Mountain, Suffolk Works, Berkley Street, Birmingham.
1863. Muir, William, 59 Shardeloes Road, New Cross, London, S.E.
1865. Murdock. William Mallabey, Barrow Hæmatite Steel Works, Barrow-in-Furness, Lancashire.
1859. Murphy, James. Railway Works, Newport, Monmouthshire.
1858. Murray. Thomas H., Engine Works, Chester-le-Street, near Fence Houses.
1863. Musgrave, John, Jun., Globe Iron Works, Bolton.

1870. Napier, James Murdoch, Messrs. David Napier and Sons, Vine Street, York Road, Lambeth, London, S.E.
1848. Napier, John, Messrs. Robert Napier and Sons, Engineers and Shipbuilders, Lancefield House, Glasgow.
1856. Napier, Robert, West Shandon, Helensburgh, near Glasgow. (*Life Member.*)
1861. Naylor, John William, Wellington Foundry, Leeds.
1858. Naylor, William, Great Indian Peninsula Railway, 3 New Broad Street, London, E.C.
1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow.
1869. Nelson, James, Bonners Field Foundry, Sunderland.
1860. Nettlefold, Joseph Henry, Screw Works, Broad Street, Birmingham.
1866. Newdigate, Albert Lewis, 14 Dover Street, Piccadilly, London, W. (*Life Member.*)
1862. Newton, William Edward, 66 Chancery Lane, London, W.C.
1858. Nichol, Peter Dale, Sunderland Engine Works, South Dock, Sunderland.
1866. Norfolk, Richard, Beverley Iron and Wagon Works, Beverley.
1850. Norris, Richard Stuart, Wilton Cottage, Kenyon, near Manchester.
1868. Norris, William Gregory, Coalbrookdale Iron Works, near Wellington, Shropshire.
1869. North, Frederic William, Mining Engineer, Rowley Hall Colliery, Rowley Regis, near Dudley.
1870. Nye, Henry, Messrs. Varrall Elwell and Poulot's Works, 9 Avenue Trudaine, Paris.

1868. O'Connor, Charles, Beaufort House, High Street, Durdham Down, Bristol.
1866. Oliver, William, Victoria Foundry, Chesterfield.
1867. Olrick, Lewis, 27 Leadenhall Street, London, E.C.
1864. Ommanney, Frederick Francis, New Bridge Foundry, Adelphi Street, Salford, Manchester.
1870. Osborn, Samuel, Clyde Steel Works, Sheffield.
1870. Osman, Joseph, Bey, Chief Engineer and Superintendent of Factories to the Khedive of Egypt, Boulac, Cairo : St. James' Hotel, 77 Piccadilly, London, W.
1867. Oughterson, George Blake, Messrs. Manlove Alliott and Co., 45 Rue d'Elbeuf, Rouen, France.
1847. Owen, William, Phœnix Wheel Tyre and Axle Works, Rotherham.

1868. Paget, Arthur, Machine Works, Loughborough.
1869. Palmer, Alfred Septimus, Mining Engineer, Quayside, Newcastle-on-Tyne.
1871. Parke, Frederick, Withnell Fire Clay Works and Cotton Mill, near Chorley, Lancashire.

1868. Parker, Frederick, Messrs. John Fowler and Co.'s Works, Steam Plough and Locomotive Works, Leeds.
1868. Parker, Henry, Harvey Villas, Olive Mount, Tranmere, Birkenhead.
1869. Parker, Thomas, Mersey Wheel Works, Stourbridge.
1865. Parkes, Alexander, Stephenson Metal Tube Works, Liverpool Street, Birmingham.
1871. Parkes, Pershouse, Tipton Chain Works, Castle Street, Tipton.
1866. Parton, Thomas, Messrs. Addenbrookes Smith and Pidcock's Works, Rough Hay Furnaces, Darlaston, near Wednesbury.
1869. Peacock, Ralph, Messrs. Beyer Peacock and Co.'s Works, Gorton Foundry, Manchester.
1869. Peacock, Ralph, Cyclops Iron Works, Goole.
1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.
1867. Pearce, Robert Webb, Carriage Superintendent, East Indian Railway, Calcutta, India.
1848. Pearson, John, 7 Old Hall Street, Liverpool.
1869. Pearson, William Hall, 50 Ann Street, Birmingham.
1866. Peel, George, Jun., Soho Iron Works, Pollard Street, Manchester.
1866. Peele, Arthur John, Messrs. Bunnett and Co., 90 Queen Street, London, E.C.; and New Cross Works, Deptford, London, S.E.
1848. Penn, John, The Cedars, Lee, London, S.E. (*Life Member.*)
1861. Perkins, Loftus, 6 Seaford Street, Regent Square, London, W.C.
1866. Perks, John Hartley, Shrubbery Iron Works, Wolverhampton.
1863. Perry, Thomas J., Highfields Engine Works, Bilston.
1865. Perry, William, Messrs. Samuel Perry and Sons, Wednesbury.
1860. Peyton, Edward, Bordesley Works, Birmingham.
1869. Pickersgill, Thomas, Mining Engineer, Waterloo Main Colliery, Leeds.
1867. Pidgeon, Daniel, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.
1856. Piggott, George, The Lions, Park Hill, Moseley, Birmingham.
1854. Pilkington, Richard, Summerdale, Trinity Road, Birchfield, Birmingham.
1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.
1859. Platt, John, M.P., Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.
1867. Platt, Samuel Radcliffe, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.
1870. Platt, William Wilkinson, Messrs. Mather and Platt, Salford Iron Works, Manchester.
1869. Player, John, Clydach Foundry, near Swansea.
1866. Plum, Thomas Edward Day, Messrs. Sharp Stewart and Co.'s Works, Atlas Works, Manchester.

1861. Plum, Thomas William, Old Park Iron Works, near Shiffnal.
1860. Ponsonby, Edward Vincent, 2 Mountjoy Park, Clonliffe Road, Dublin.
1866. Porter, Charles Talbot, Allen Engine Works, Fourth Avenue, Harlem, New York, United States.
1869. Potter, William Aubone, Mining Engineer, Cramlington House, Cramlington, Northumberland.
1864. Potts, Benjamin Langford Foster, 200 Camberwell Grove, London, S.E.
1851. Potts, John Thorpe, 5 Pemberton Square, Boston, Massachusetts, United States.
1870. Powell, Thomas, Messrs. Thomas and T. Powell, 23 Rue St. Julien, Rouen, France.
1867. Powell, William, Harbour Works, Douglas, Isle of Man.
1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.
1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.
1856. Preston, Francis, Ancoats Bridge Works, Ardwick, Manchester.
1866. Price, John, Chief Surveyor, Underwriters' Registry for Iron Vessels, 37 West Sunniside, Sunderland.
1869. Purves, John, Superintending Engineer, Liverpool New York and Philadelphia Steam Ship Co., Water Street, Liverpool.
1866. Putnam, William, Darlington Forge. Darlington.

1870. Radcliffe, William, Messrs. Charles Cammell and Co.'s Works, Cyclops Steel and Iron Works, Sheffield.
1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.
1862. Rake, Alfred Stansfield, St. Nicholas Buildings, Newcastle-on-Tyne.
1864. Ramage, Robert, Locomotive Superintendent, Midland Great Western Railway, Dublin.
1847. Ramsbottom, John, Harewood Lodge, Mottram, near Manchester.
1866. Ramsden, James, Abbot's Wood, Barrow-in-Furness, Lancashire.
1860. Ransome, Allen, Jun., 304 King's Road, Chelsea, London, S.W.
1869. Ransome, Robert Charles, Messrs. Ransomes Sims and Head, Orwell Works, Ipswich.
1862. Ransome, Robert James, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich.
1867. Ratcliff, Daniel Rowlinson, Messrs. Thomas Milner and Son, Phœnix Safe Works, Liverpool.
1867. Ratliffe, George, Lancashire Steel Works, Gorton, Manchester.
1862. Ravenhill, John R., Glass House Fields, Ratcliff, London, E.
1870. Reed, Edward James, C.B., 60 Inverness Terrace, Lancaster Gate, Hyde Park Gardens, London, W.

1859. Rennie, George Banks, 20 Lowndes Street, Lowndes Square, London, S.W.
1862. Reynolds, Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.
1866. Richards, Edward Windsor, Ebbw Vale Iron Works, near Beaufort, Monmouthshire.
1856. Richards, Josiah, Pontypool Iron and Tinplate Works, Pontypool.
1863. Richardson, Edward, Lyttelton and Christchurch Railway, Christchurch, New Zealand.
1865. Richardson, John, Methley Park, near Leeds.
1859. Richardson, William, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.
1863. Rigby, Samuel, Cock Hedge Mill, Warrington.
1871. Rigg, John, Deputy Locomotive Superintendent, London and North Western Railway, Crewe.
1848. Robertson, Henry, Great Western Railway, Shrewsbury.
1865. Robey, Robert, Perseverance Iron Works, Lincoln.
1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and Westwood, Leek, near Stoke-upon-Trent.
1865. Robinson, John, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.
1866. Robson, Thomas, Mining Engineer, Lumley Colliery, Fence Houses.
1868. Rogers, William, Imperial Railway Department, Hiogo, Japan.
1871. Rollo, David, Messrs. Jack Rollo and Co., Victoria Engine Works, Sandon Dock, Liverpool.
1853. Ronayne, Joseph P., 4 Harbour Hill, Queenstown, Ireland.
1867. Rose, Henry Fullwood, Albert Iron Works, Moxley, near Wednesbury.
1866. Rose, Thomas, Bradley Iron Works, near Bilston.
1867. Rose, Thomas, Machine Works, 37 Victoria Street, Manchester.
1869. Rose, William Napoleon, Albert Iron Works, Moxley, near Wednesbury.
1866. Rosthorn, Joseph De, Messrs. Rosthorn Brothers, Vienna.
1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Peterborough.
1857. Routledge, William, 4 Parsonage Buildings, Blackfriars, Manchester.
1860. Rumble, Thomas William, 15 George Street, Mansion House, London, E.C. (*Life Member.*)
1847. Russell, John Scott, 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1867. Ruston, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.
1866. Ryland, Frederick, Messrs. Kenrick's Works, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, Avonside Engine Works, St. Philip's, Bristol.
1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1868. Sacré, Edward Antoine, 26 Parliament Street, Westminster, S.W.
1864. Said, Colonel M., Bey, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 22 Great George Street, Westminster, S.W.)
1859. Salt, George, Saltaire, near Bradford, Yorkshire.
1864. Samuda, Joseph D'Aguilar, M.P., Iron Ship Building Yard, Isle of Dogs, Poplar, London, E.
1848. Samuel, James, 26 Great George Street, Westminster, S.W.
1857. Samuelson, Alexander, 27 Cornhill, London, E.C.
1865. Samuelson, Bernhard, M.P., Britannia Iron Works, Banbury.
1865. Sandberg, Christer Peter, Engineer, Swedish Government Railway Service; 19 Great George Street, Westminster, S.W.
1861. Sanderson, George Grant, 2 Kenwood Road, Sharrow, near Sheffield.
1864. Sanderson, John, Weardale and Shildon District Water Works, Waskerley Park Reservoir, near Darlington.
1869. Scarlett, James, 14 St. Ann's Square, Manchester.
1869. Schanschieff, Alexandre, Engineer, Russian Imperial Navy, 30 Galernaia, St. Petersburg.
1866. Scholtze, Aleksander, Messrs. Scholtze Brothers, Engineers and Boiler Makers, Warsaw, Poland.
1865. Scott, Edward, 34 St. Ann's Street, Cross Street, Manchester.
1868. Scott, George Lamb, Crown Iron Works, Heywood Street, Clowes Street, West Gorton, Manchester.
1861. Scott, Walter Henry, Locomotive and Carriage Superintendent, Mauritius Railways, Port Louis, Mauritius: (or care of James Murray, 16 Brunswick Street, Barnsbury Road, London, N.)
1868. Scriven, Charles, Leeds Old Foundry, Marsh Lane, Leeds.
1864. Seddon, John, 98 Wallgate, Wigan.
1857. Selby, George Thomas, Smethwick Tube Works, Birmingham.
1867. Selby, Millin, Teakova Cotton Mill, near Ivanova, Vladimir, Russia: (or care of Atherton T. Selby, Atherton Old Hall, Leigh, near Manchester.)
1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.
1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.
1867. Sharpe, Charles James, 17B Great George Street, Westminster, S.W.
1862. Sharpe, William John, 1 Victoria Street, Westminster, S.W.
1869. Sharrock, Samuel, Windsor Iron Works, Spekeland Street, Edge Hill, Liverpool.
1864. Shaw, Duncan, Mining Engineer, Cordoba, Spain.
1856. Shelley, Charles Percy Bysshe, 113 Victoria Street, Westminster, S.W.

1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.

1859. Shuttleworth, Joseph, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

1851. Siemens, Charles William, 3 Great George Street, Westminster, S.W.

1871. Simon, Henry, 7 St. Peter's Square, Manchester.

1847. Sinclair, Robert, 4 Westminster Chambers, Victoria Street, Westminster, S.W.

1857. Sinclair, Robert Cooper, Hartshill, near Atherstone.

1859. Slater, Isaac, Gloucester Wagon Works, Gloucester.

1853. Slaughter, Edward, Avonside Engine Works, St. Philip's, Bristol.

1866. Smethurst, Joseph, Guide Bridge Iron Works, Audenshaw, near Manchester.

1866. Smith, Edward Fisher, The Priory Offices, Dudley.

1866. Smith, Fereday, Bridgewater Offices, Manchester.

1860. Smith, Henry, Brierley Hill Iron Works, Brierley Hill.

1860. Smith, John, Brass Foundry, Traffic Street, Derby.

1857. Smith, Josiah Timmis, Ulverstone Hæmatite Iron Works, Barrow-in-Furness, Lancashire.

1859. Smith, Matthew, Caledonia Wire Mills, Halifax.

1857. Smith, William, 19 Salisbury Street, Adelphi, London, W.C.

1866. Smith, William, Eglinton Engine Works, Glasgow.

1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester.

1857. Snowdon, Thomas, 147 High Street, Stockton-on-Tees.

1871. Soames, Peter, 10 Southampton Street, Strand, London, W.C.

1859. Sokoloff, Colonel Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia : (or care of Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.)

1858. Sörensen, Bergerius, Engineer-in-Chief, Royal Norwegian Navy Department, Horten Dockyard, Norway : (or care of Henry Tottie, 5 Great Winchester Street Buildings, London, E.C.)

1865. Sparrow, Arthur, Lane End Iron Works, Longton, near Stoke-upon-Trent.

1865. Sparrow, William Mander, Osier Bed Iron Works, Wolverhampton.

1866. Spencer, Eli, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne.

1853. Spencer, Thomas, Blackladies, Brewood, near Stafford.

1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.

1864. Spittle, Thomas, Cambrian Iron Foundry, Newport, Monmouthshire.

1862. Stableford, William, Oldbury Carriage Works, near Birmingham.

1869. Stabler, James, Messrs. Shand Mason and Co., Fire Engine Works, 75 Upper Ground Street, Blackfriars Road, London, S.E.

1869. Stenson, Foster, Burton Iron Works, Burton-on-Trent.
1868. Stenson, William Towndrow, Whitwick Colliery, Coalville, near Leicester.
1866. Stephens, John Classon, Messrs. Ross Stephens and Walpole, North Wall Iron Works, Dublin.
1868. Stephenson, George Robert. 24 Great George Street, Westminster, S.W.
1866. Stevenson, John, Acklam Iron Works. Middlesbrough.
1867. Stevenson, Robert, Mining Engineer, Clay Cross. near Chesterfield.
1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and 92 Lancaster Gate, Hyde Park Gardens, London, W.
1851. Stewart, John, Blackwall Iron Works, Russell Street, Blackwall, London, E.
1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.
1864. Stokes, James Folliott, Punjab Club, Lahore, India: (or care of Charles P. B. Shelley, 113 Victoria Street, Westminster, S.W.)
1863. Storey, John Henry, Knott Mill Brass and Copper Works, Little Peter Street, Manchester.
1862. Strong, Joseph F., Resident Engineer, East Indian Railway, Cawnpore, India.
1865. Stroudley, William, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton.
1861. Sumner, William, 2 Brazenose Street, Manchester.
1860. Swindell, James Evers, Parkhead Iron Works, Dudley.
1864. Swindell, James Swindell Evers, Cradley Iron Works, near Brierley Hill.
1859. Swingler, Thomas, Victoria Foundry, Litchurch, near Derby.

1861. Tangye, James, Cornwall Works, Clement Street, Birmingham.
1859. Tannett, Thomas, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.
1861. Taylor, George, Messrs. Taylor Brothers and Co., Clarence Iron Works, Leeds.
1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.
1862. Taylor, John, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.
1867. Taylor, Joseph, Derwent Foundry, 99 Constitution Hill, Birmingham.
1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.
1868. Taylor, Samuel, Messrs. Taylor Brothers and Co., Clarence Iron Works, Leeds.
1864. Tennant, Charles, The Glen, Innerleithen, near Edinburgh. (*Life Member.*)
1867. Thomas, Joseph Lee, 16 Holland Road, Kensington, London, W.

1864. Thomas. Thomas, Bronygarn Villa, Roath, Cardiff.
1857. Thompson, Robert, Haigh Foundry, near Wigan.
1862. Thompson, William, Messrs. Thompson and Boyd, Spring Gardens Engine Works, Newcastle-on-Tyne.
1868. Thomson, John, Engine Works, 36 Finnieston Street, Glasgow.
1870. Thomson. William Sparks, Railway Buffer and Spring Works, 154 West Regent Street, Glasgow.
1865. Thorn, Alexander, Cremorne Wharf, Chelsea, London, S.W.
1868. Thornewill. Robert, Burtou Iron Works, Burton-on-Trent.
1861. Thwaites, Robinson, Messrs. Thwaites and Carbutt, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1862. Tolmé, Julian Horn, 1 Victoria Street, Westminster, S.W.
1857. Tomlinson, Joseph. Jun., West Bute Street, Cardiff.
1867. Tonks, Edmund, Brass Works, Moseley Street, Birmingham.
1856. Tosh, George, North Lincolnshire Iron Works, Frodingham, near Brigg.
1860. Townsend, Thomas C., 16 Talbot Chambers, Shrewsbury.
1865. Trow, John James, Messrs. William Trow and Sons, Union Foundry, Wednesbury.
1862. Troward, Charles, 8 Sussex Terrace, Camden Town, London. N.W.
1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich.
1867. Turner. Henry, 27 Netherfield Road North, Liverpool.
1867. Tweddell, Ralph Hart, Engine Works, Richmond Street, Sunderland.
1856. Tyler, Captain Henry Wheetley, R.E., Railway Department, Board of Trade, Whitehall, London, S.W.

1862. Upward, Alfred, Engineer, Chartered Gas Works, 146 Goswell Street, London, E.C.

1868. Vallance, Frederick Bevoley. Alicel Engine Works, Bridge Street, Greenwich, S.E.
1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.
1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.
1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1856. Waddington, John. 35 King William Street, London Bridge, London, E.C.
1865. Wainwright, William, Great Western Railway, Locomotive Department, Worcester.
1863. Wakefield. John, Locomotive Superintendent Dublin Wicklow and Wexford Railway, Dublin.

1870. Walker, Alfred, Albion Iron Works, Aldwark, York.
1867. Walker, Benjamin, Goodman Street Works, Hunslet, Leeds.
1864. Walker, Bernard Peard, Junction Cut Nail Works, Wolverhampton.
1867. Walker, Charles Clement, Midland Iron Works, Donnington, near Newport, Shropshire.
1847. Walker, Thomas, Patent Shaft Works, Wednesbury.
1863. Walker, William Hugill, Messrs. Walker Eaton and Co., Wicker Iron Works, Sheffield.
1863. Wallace, William, Superintending Engineer, Montreal Ocean Steam Ship Works, Boundary Street North, Liverpool.
1865. Waller, George Arthur, Messrs. Guinness, James' Gate, Dublin.
1868. Wallis, Herbert, Assistant Locomotive Superintendent, Grand Trunk Railway, Montreal, Canada.
1865. Walpole, Thomas, Messrs. Ross Stephens and Walpole, North Wall Iron Works, Dublin.
1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Glover Street, Birmingham.
1856. Wardle, Charles Wetherell, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.
1852. Warham, John R., Burton Iron Works, Burton-on-Trent.
1867. Watkin, William John Laverick, Mining Engineer, Pemberton Colliery, near Wigan.
1862. Watkins, Richard, Canal Iron Works, Poplar, London, E.
1866. Watson, Robert, Engineer, Black Boy Collieries, Bishop Auckland.
1862. Webb, Francis William, Locomotive Superintendent, London and North Western Railway, Crewe.
1860. Weild, William, Gorebrook Iron Works, Longsight, Manchester.
1862. Wells, Charles, Moxley Iron Works, near Bilston.
1871. West, Henry Joseph, Messrs. Siebe and West, Mason Street, Lambeth, London, S.E.
1862. Westmacott, Percy G. B., Sir William G. Armstrong and Co., Elswick Engine Works, Newcastle-on-Tyne.
1867. Weston, Thomas Aldridge, care of William T. Watts, 78 Parade, Birmingham.
1867. Wheatley, Thomas, Locomotive Superintendent, North British Railway, Edinburgh.
1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston.
1864. White, Isaiah, Messrs. Portilla and White, Engineers and Iron Ship Builders, Seville, Spain : (or care of Isaac White, Pontardulais, Llanelly.)
1868. Whitehead, Peter Ormerod, Ilex Cotton Mill, Rawtenstall, near Manchester.
1859. Whitham, James, Perseverance Iron Works, Kirkstall Road, Leeds.

1863. Whitley, Joseph, New British Iron Works, Corngreaves near Birmingham.
1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry
1866. Whitwell, Thomas, Thornaby Iron Works, Stockton-on-Tees.
1847. Whitworth, Sir Joseph, Bart., Chorlton Street, Manchester; and The Firs, Fallowfield, Manchester.
1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford, Yorkshire.
1863. Wicksteed, Thomas, 8 Torquay Terrace, Headingley, near Leeds. (*Life Member.*)
1868. Wigham, John Richardson, 35 Capel Street, Dublin.
1868. Wigram, Reginald, Messrs. John Fowler and Co.'s Works, Steam Plough and Locomotive Works, Leeds.
1867. Wilkes, Gilbert, Tube Works, Bordesley Mills, Birmingham.
1867. Wilkes, John, Tube Works, Bordesley Mills, Birmingham.
1868. Wilkieson, Lt.-Colonel Charles Vaughan, R.E., care of Messrs. Richardson and Co., 13 Pall Mall, London, S.W.
1865. Williams, Edward, Messrs. Bolckow Vaughan and Co.'s Iron Works, Middlesbrough.
1847. Williams, Richard, Patent Shaft Works, Wednesbury.
1859. Williams, Richard Price, 9 Great George Street, Westminster, S.W.
1869. Williams, Walter, Wednesbury Oak Iron Works, Tipton.
1870. Willman, Charles, 3 Cleveland Terrace, Middlesbrough.
1856. Wilson, Edward, 9 Dean's Yard, Westminster, S.W.
1859. Wilson, George, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.
1867. Wilson, Henry, Phœnix Brass Works, Stockton-on-Tees.
1865. Wilson, James Edwards, 23 New Street, Spring Gardens, London, S.W.
1863. Wilson, John Charles, 17 Gracechurch Street, London, E.C.
1857. Wilson, Robert, Bridgewater Foundry, Patricroft, near Manchester.
1860. Wilson, William, 4 Victoria Street, Westminster, S.W.
1865. Winby, Clifford Etches, Messrs. Winby Brothers, Atlas Iron Works, Cardiff.
1867. Winby, Frederick Charles, Messrs. Winby Brothers, Atlas Iron Works, Cardiff.
1862. Winby, William Edward, Old Park Iron Works, Wednesbury.
1859. Winter, Thomas Bradbury, 28 Moorgate Street, London, E.C.
1871. Withy, Edward, Messrs. Withy and Alexander, Middleton Iron Shipbuilding Yard, Hartlepool.
1868. Wood, Lindsay, Mining Engineer, Hetton Colliery, Hetton, near Fence Houses.
1869. Wood, Thomas James Vickers, Springfield Mill, Cleckheaton, near Normanton.

1851. Woodhouse, John Thomas, Mining Engineer, Midland Road. Derby.
1858. Woods, Hamilton, Liver Foundry, Ordsal Lane, Salford, Manchester.
1860. Worthington, Samuel Barton, Engineer, London and North Western Railway, Manchester.
1866. Wray. William, Ship Building Yard. Burton Stather, near Brigg.
1866. Wren, Henry. Messrs. Wren and Hopkinson, London Road Iron Works, Manchester.
1870. Wright, George Benjamin, Goscote Iron Works, near Walsall.
1867. Wright, John Turner, Universe Rope Works, Garrison Street, Birmingham.
1859. Wright, Joseph, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham.
1860. Wright, Joseph, Neptune Forge, Tipton Green, Dudley.
1863. Wright, Owen, Broadwell Forge. Oldbury, near Birmingham.
1863. Wright, Peter. Railway Wheel Vice and Anchor Works, Dudley.
1871. Wright, William, District Engineer, Cornwall Railway, Lostwithiel.
1871. Wrightson, Thomas, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.
1865. Wyllie, Andrew, Messrs. Forrester and Co., Vauxhall Foundry, Liverpool.

1861. Yule, William, 102 New Canal, St. Petersburg.

HONORARY LIFE MEMBERS.

1865. Downing, Samuel, LL.D., Trinity College, Dublin.
1847. Fairbairn, Sir William, Bart., The Polygon, Ardwick, Manchester.
1867. Morin, General Arthur, Director, Conservatoire National des Arts et Métiers, Paris.
1867. Tresca, Henri, Engineer Sub-Director, Conservatoire National des Arts et Métiers, Paris.

ASSOCIATES.

1865. Barker, Frederick, Leeds Iron Works, Leeds.
1868. Beale, Montague. 1 Great Winchester Street Buildings. London, E.C.
1867. Blinkhorn, William, London and Manchester Plate Glass Works, Sutton, St. Helen's.
1866. Crossley, John, British Plate Glass Works, Ravenhead, near St. Helen's.
1867. Dewhurst, John Bonny, Bellevue Cotton Mills, Skipton.
1863. Fisher, John, Priory Street, Dudley.
1863. Forster, George Emmerson, Contractor's Office, Washington, County Durham.

1865. Gössell, Otto, 22 Moorgate Street, London, E.C.
1865. Hall, John, 56 King Street, Manchester.
1869. Jones, John, Iron Trade Offices, Royal Exchange, Middlesbrough.
1858. Lawton, Benjamin C., 48 Westgate Street, Newcastle-on-Tyne.
1859. Leather, John Towlerton, Leventhorpe Hall, near Leeds. (*Life Associate.*)
1865. Longsdon, Alfred, 11 New Broad Street, London, E.C.
1860. Manby, Cordy, Tower Street, Dudley.
1868. Matthews, Thomas Bright, Globe Steel Works, Sheffield.
1867. Neave, William Alexander, 14 King Street, Birkenhead.
1865. Parry, David, Leeds Iron Works, Leeds.
1864. Parsons, Charles T., Ann Street, Birmingham.
1871. Patterson, John, Liverpool and Manchester District Bank, Spring Gardens, Manchester.
1856. Pettifor, Joseph, Midland Railway, Derby.
1867. Roe, Thomas, Jun., Siddals Road, Derby.
1859. Sherriff, Alexander Clunes, M.P., Great Western Railway, Worcester.
1863. Storey, Thomas R., Deptford Brass Works, Sunderland.
1864. Tennant, John, St. Rollox Chemical Works, Glasgow. (*Life Associate.*)
1864. Thornton, Falkland Samuel, Bradford Street, Birmingham.
1869. Varley, John, Farnley Iron Works, Leeds.
1865. Warden, Thomas, Lionel Street, Birmingham.
1858. Waterhouse, Thomas, Claremont Place, Sheffield. (*Life Associate.*)
1867. Watts, William Thomas, 78 Parade, Birmingham.
1865. Whitley, Joseph, Bowman Lane, Leeds.
1870. Wright, Edwin Arthur, Messrs. Wright and North's Works, Monmore Iron Works, Wolverhampton.

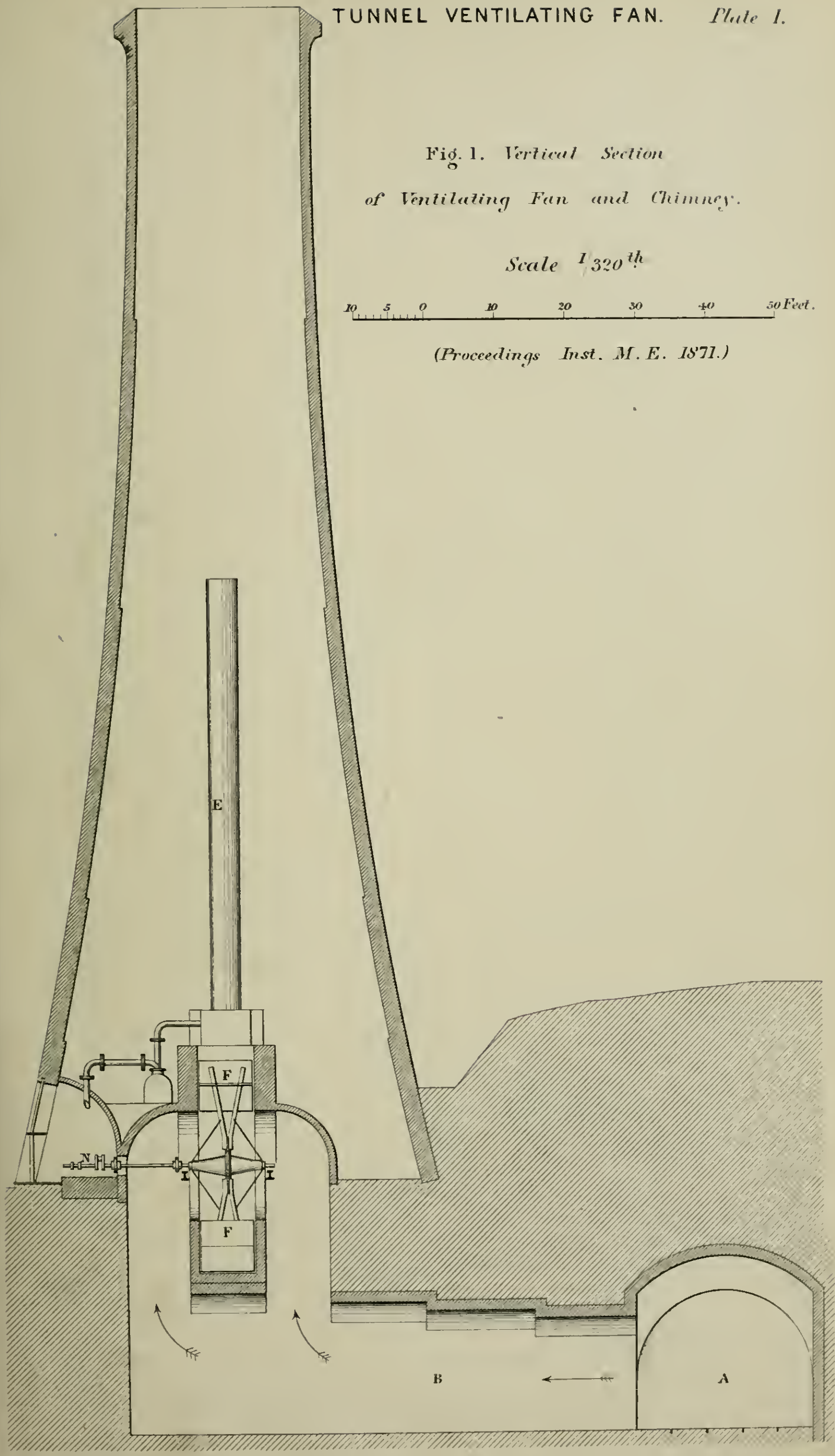
GRADUATES.

1869. Bainbridge, Emerson, Nunnery Colliery Offices, Sheffield.
1869. Blake, Frederick William, Birmingham Heath Boiler Works, Spring Hill, Birmingham.
1866. Butler, Thomas Snowden, Kirkstall Forge, near Leeds.
1867. Cuss, Nevil John, Messrs. Cuss and Kell, Chisledon Foundry, Swindon.
1868. Dugard, William Henry, 77 Lower Loveday Street, Birmingham.
1869. Fenwick, Clennell, 44A Coal Exchange, Lower Thames Street, London, E.C.
1867. Flavel, Sidney, Jun., Eagle Foundry, Leamington.
1850. Glydon, George, Spring Hill Tube and Metal Works, Eyre Street, Birmingham.
1867. Holland, George, care of John Holland, Navigation Old Yard, Castle, Northwich.

1866. Humphrys, Robert Harry, Deptford Pier. London, S.E.
1867. Jones, George Edward, Horseley Iron Works, Tipton.
1868. Mappin, Frank, Messrs. Thomas Turton and Sons' Works, Sheaf Works. Sheffield.
1867. Mayhew, Horace, Mining Engineer, Wigan.
1867. Mitchell, John, Swaithe Colliery, Barnsley.
1868. Moor, William, Jun., Hetton Colliery, Hetton, near Fence Houses.
1867. Pearson, John Edward, Spring Colliery, Ince Hall, near Wigan.
1870. Pearson, Thomas Henry. Moss Side Iron Works, Ince, near Wigan.
1870. Smith, Michael Holroyd, Caledonia Wire Mills, Halifax.
1871. Thurgood, Ernest Charles, Messrs. Nettlefold's Screw Works, Smethwick, near Birmingham.
1868. Wicksteed, Joseph Hartley, Well House Foundry, Meadow Road, Leeds.
1867. Wright, John Roper, Landore Steel Works, Swansea.

Fig. 1. *Vertical Section of Ventilating Fan and Chimney.*

Scale $^1/_{320}$th



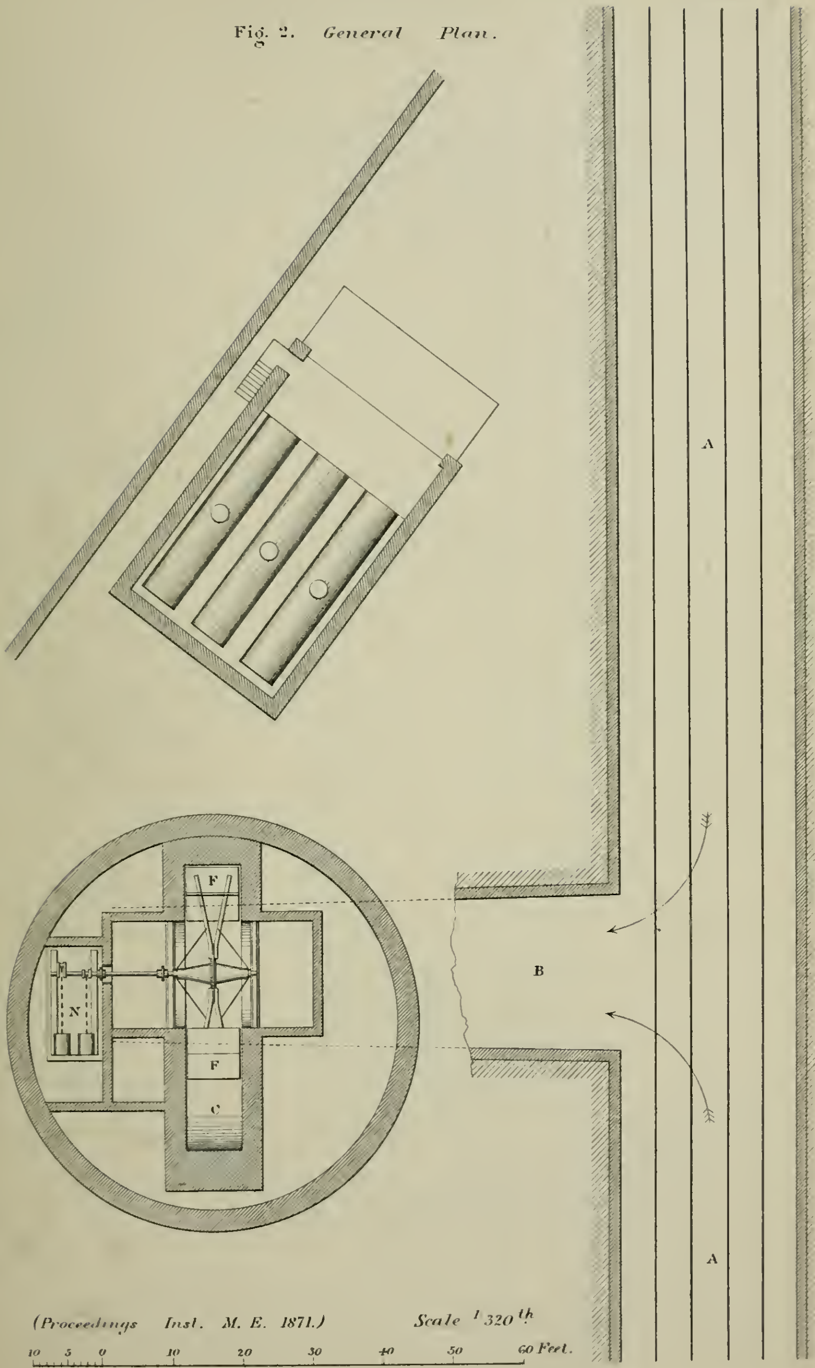
(Proceedings Inst. M. E. 1871.)

[illegible]

TUNNEL VENTILATING FAN.

Plate 2.

Fig. 2. *General Plan.*



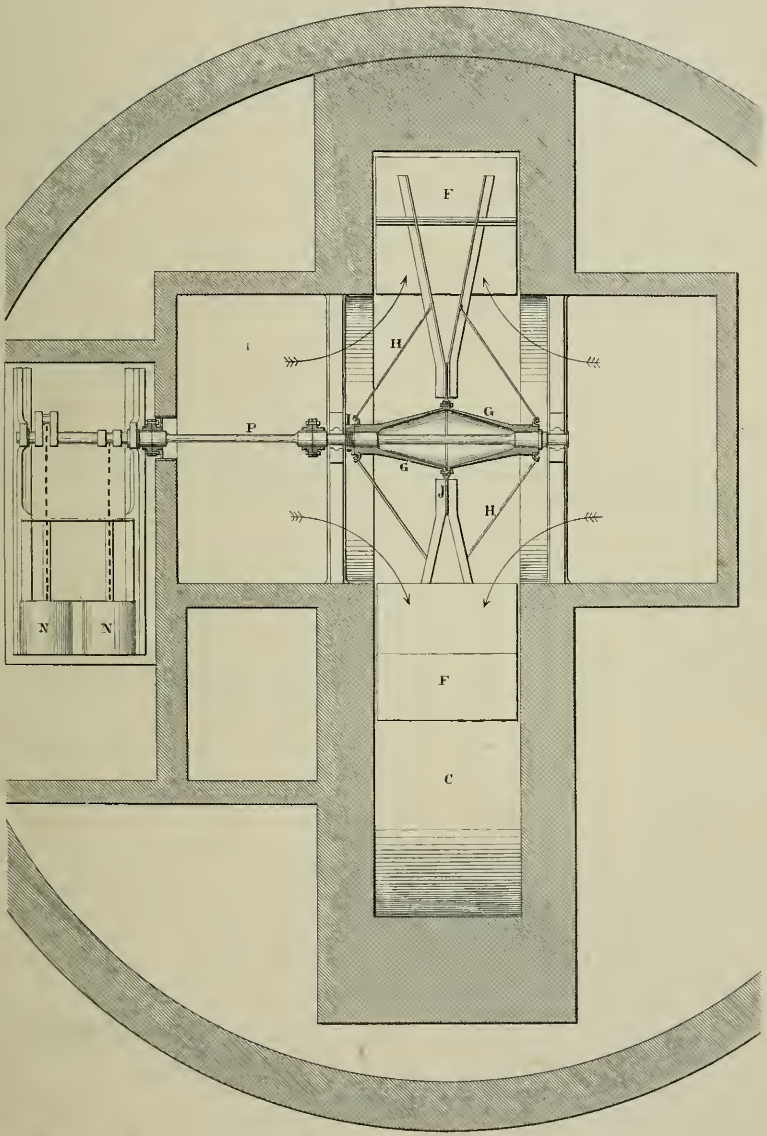
(Proceedings Inst. M. E. 1871.)

Scale 1/320th

10 5 0 10 20 30 40 50 60 Feet.

TUNNEL VENTILATING FAN. *Plate 3.*

Fig. 3. *Sectional Plan of Fan*



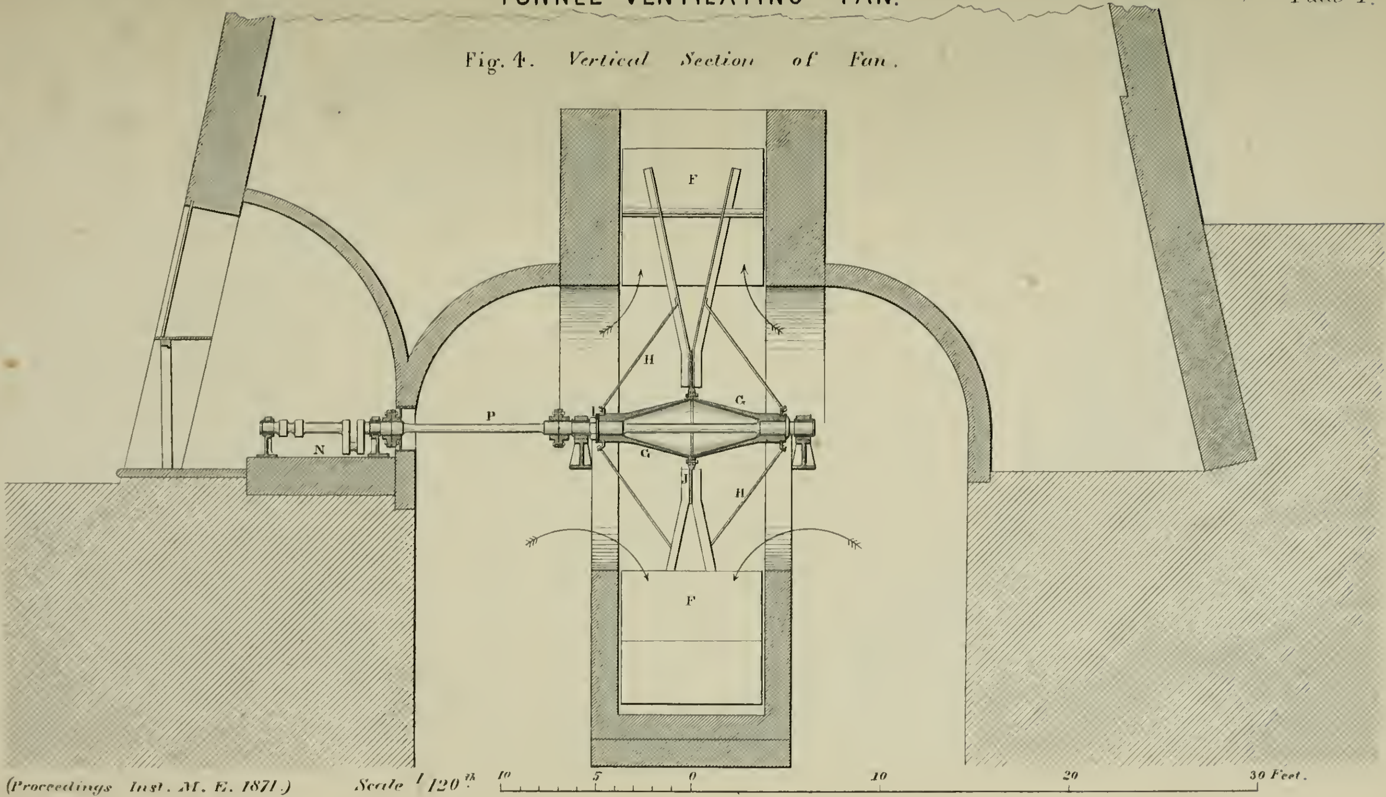
(Proceedings Inst. M. E. 1871.)

Scale 1/120th

10 5 0 10 20 30 Feet.

TUNNEL VENTILATING FAN.

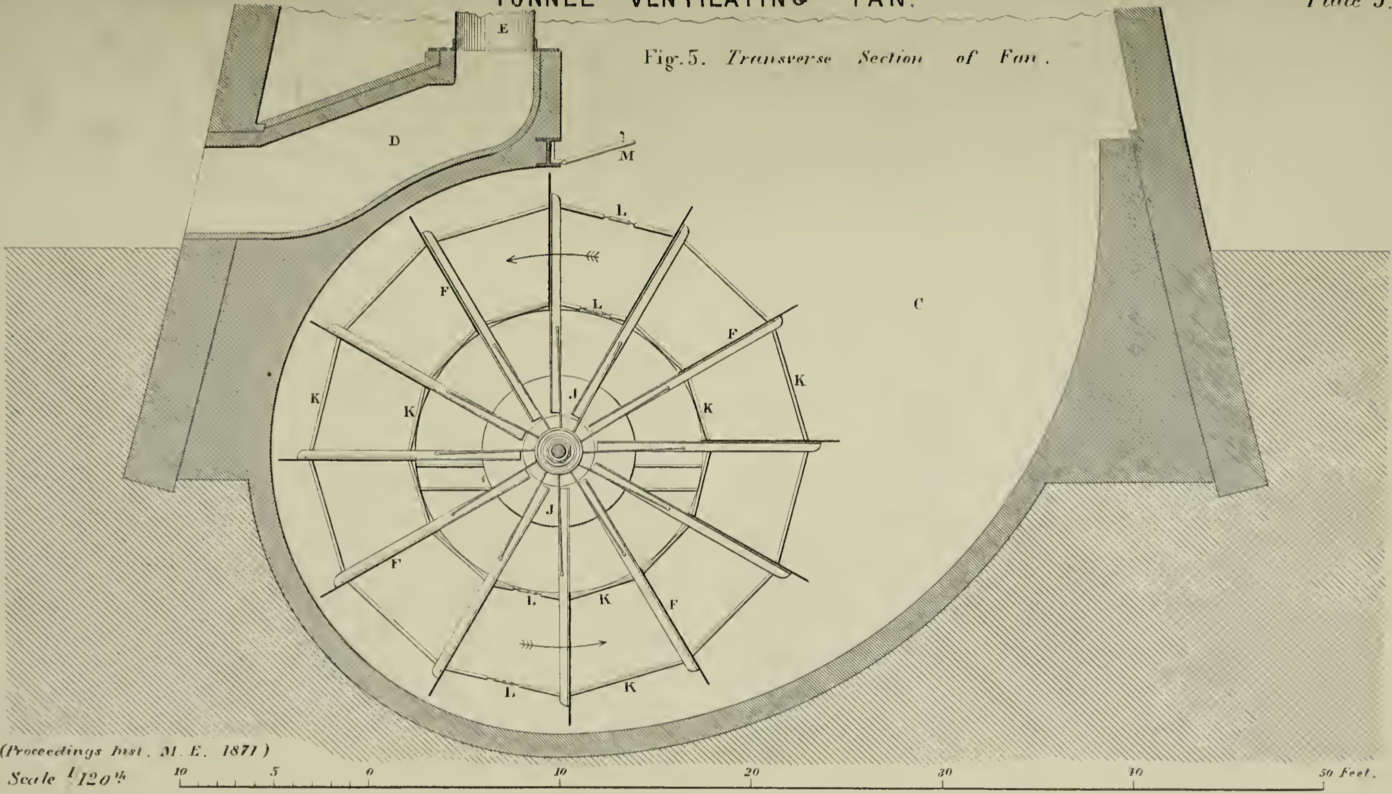
Fig. 4. Vertical Section of Fan.



(Proceedings Inst. M. E. 1871.) *Scale 1/120th.*

TUNNEL VENTILATING FAN.

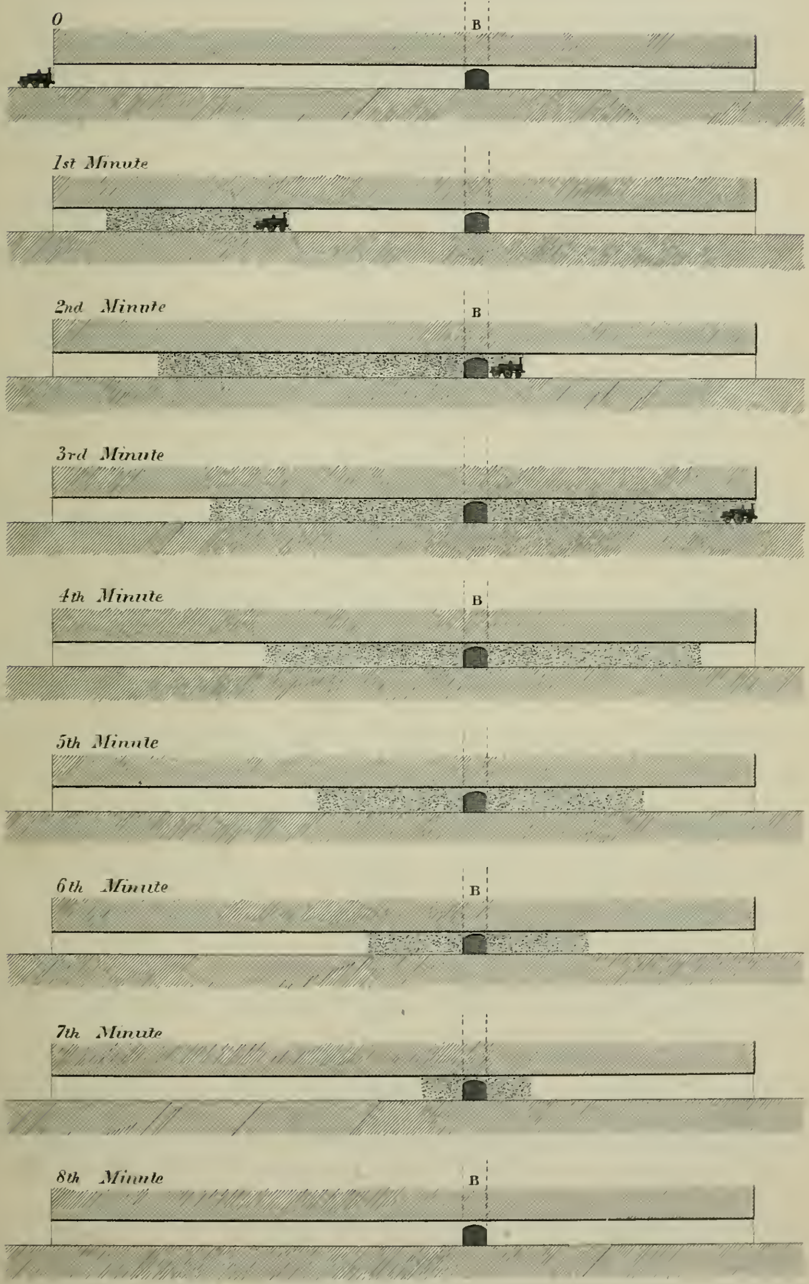
Fig. 5. *Transverse Section of Fan.*



(Proceedings Inst. M. E. 1871)

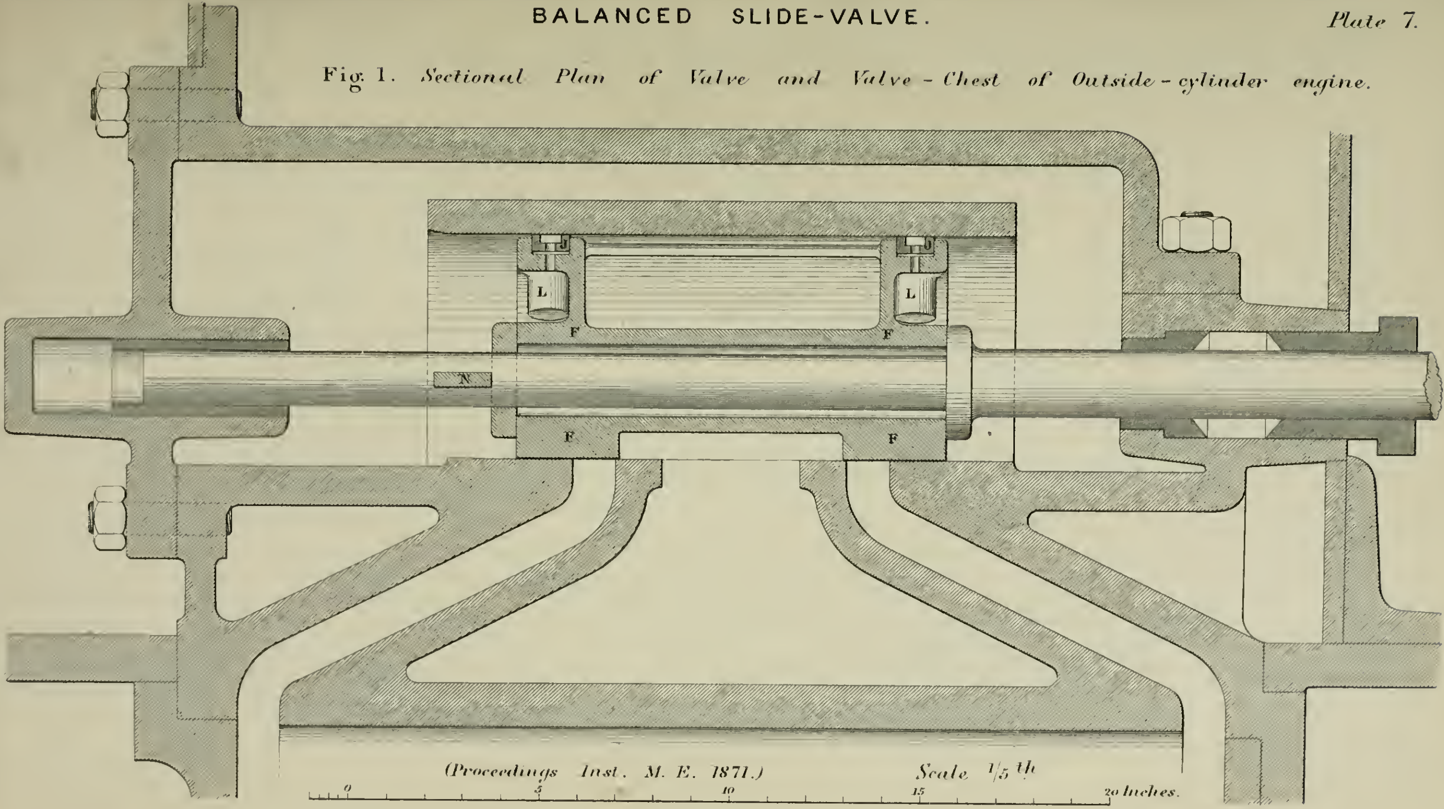
Scale 1/120th

Fig. 6. *Diagrams of Progress of Ventilation.*



BALANCED SLIDE-VALVE. *Plate 7.*

Fig. 1. *Sectional Plan of Valve and Valve-Chest of Outside-cylinder engine.*

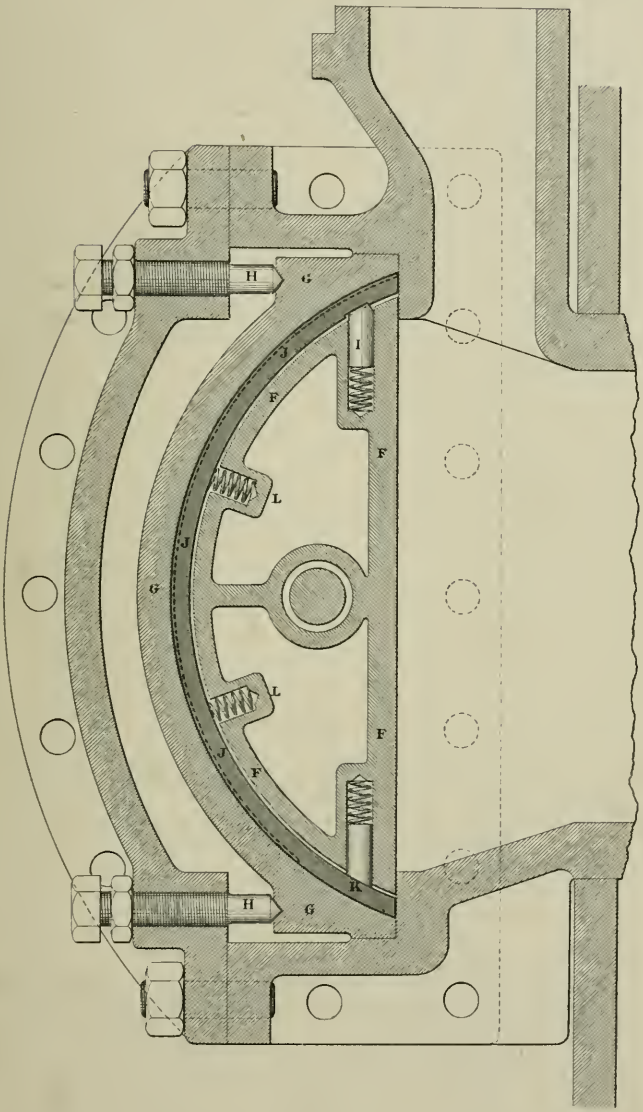


(Proceedings Inst. M. E. 1871.) *Scale 1/5 th*

BALANCED SLIDE-VALVE.

Plate 8.

Fig. 2. *Transverse Section of Valve and Valve-Chest of Outside-cylinder engine.*



(Proceedings Inst. M. E. 1871.)

Scale $\frac{1}{5}$*th*

0 5 10 15 *Inches.*

[illegible]

Fig. 3. *Back of Valve.*

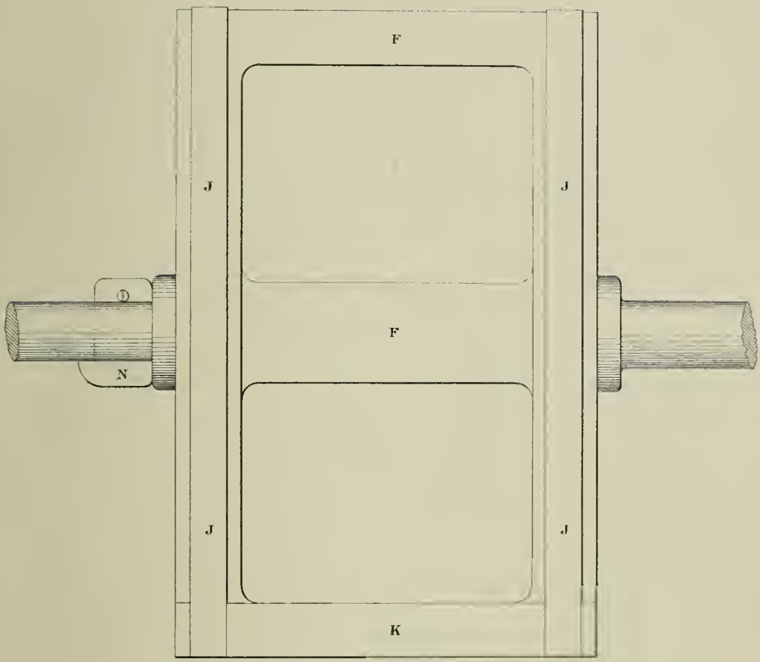


Fig. 4. *Section of Packing with Radial Springs.*

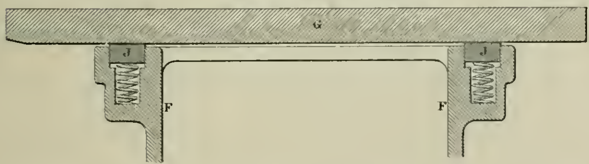
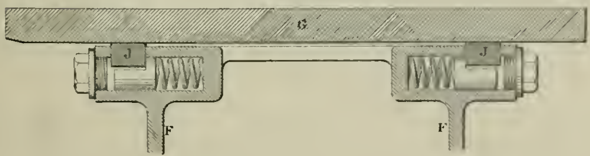
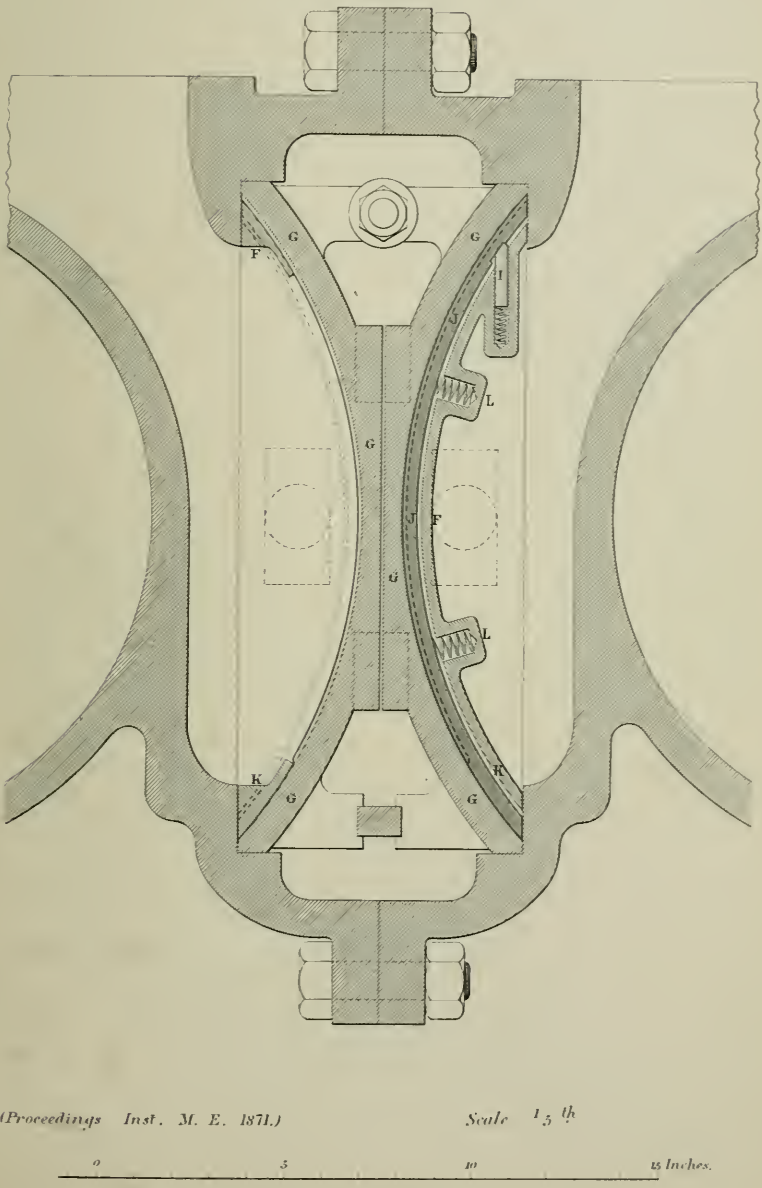


Fig. 5. *Section of Packing with Lateral Springs.*



 Scale 1/5th

Fig. 6. *Transverse Section of Valve and Valve-Chest of Inside-cylinder engine.*

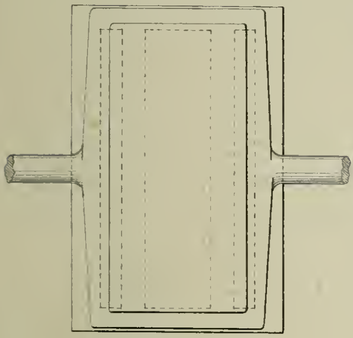


 Scale 1/5 th

BALANCED SLIDE-VALVE. *Plate 11.*

Ordinary Unbalanced Locomotive Slide-Valve.

Fig. 7. *Back of Valve.*



Scale 1/10 th.

Fig. 8 *First third of stroke*

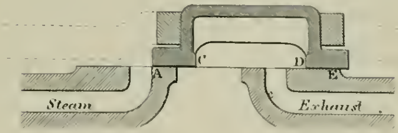


Fig. 9 *Second third of stroke.*

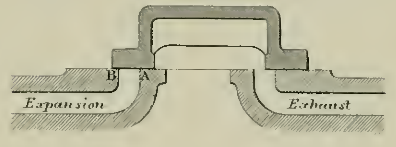


Fig. 10 *Last third of stroke.*

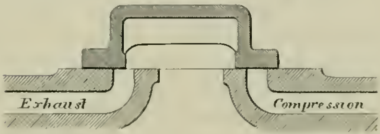
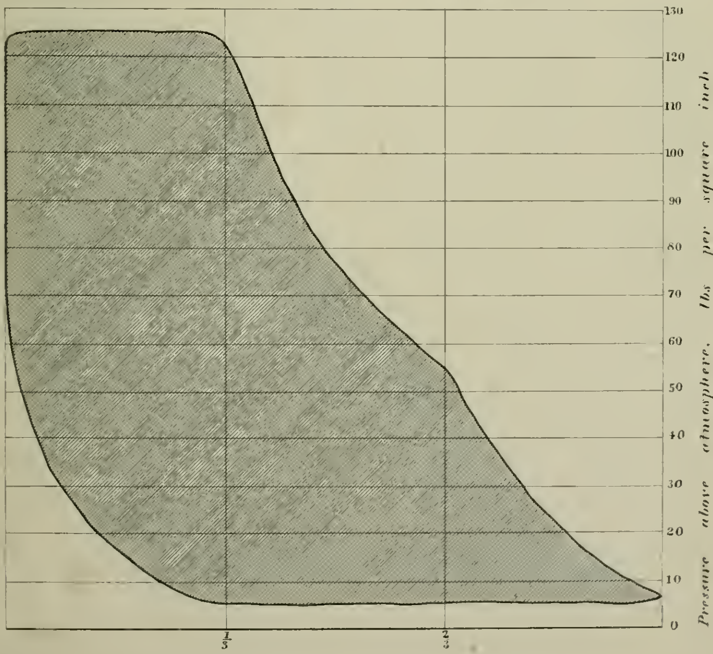
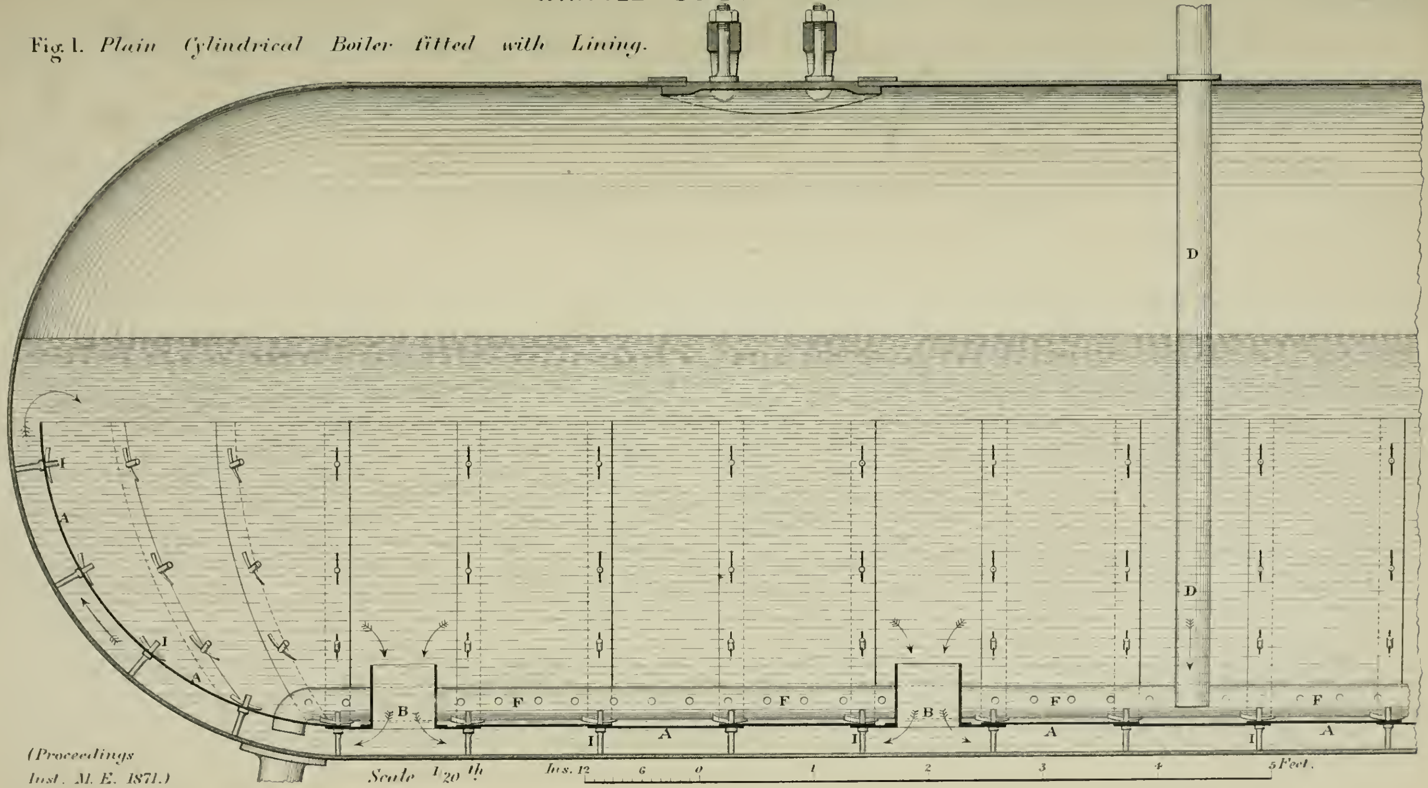


Fig. 11. *Approximate Indicator Diagram.*



WHITTLE BOILER LINING.

Fig. 1. *Plain Cylindrical Boiler fitted with Lining.*



(Proceedings Inst. M. E. 1871.)

WHITTLE BOILER LINING.

Plate 13.

Transverse Sections of Plain Cylindrical Boilers fitted with Lining.

Fig. 2. *Lining with Circular Holes at bottom.*

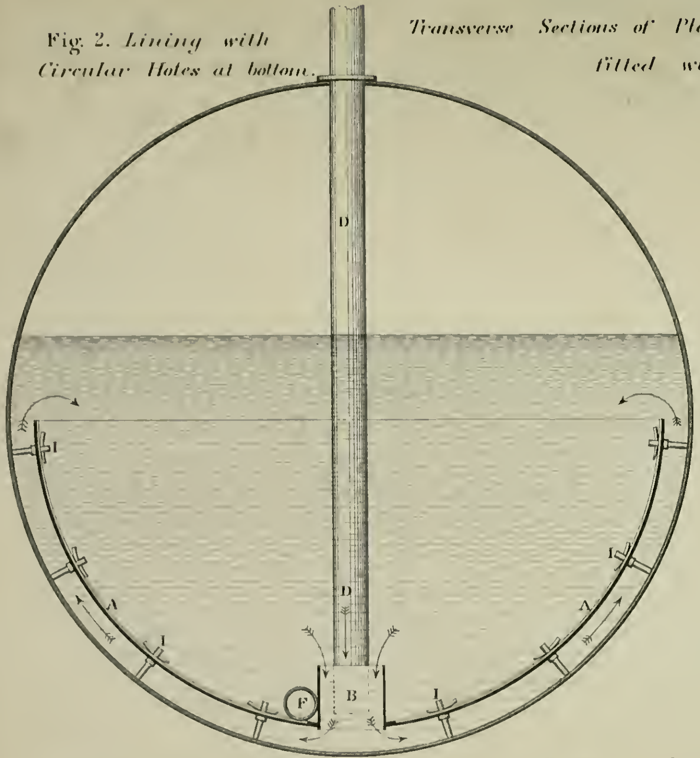
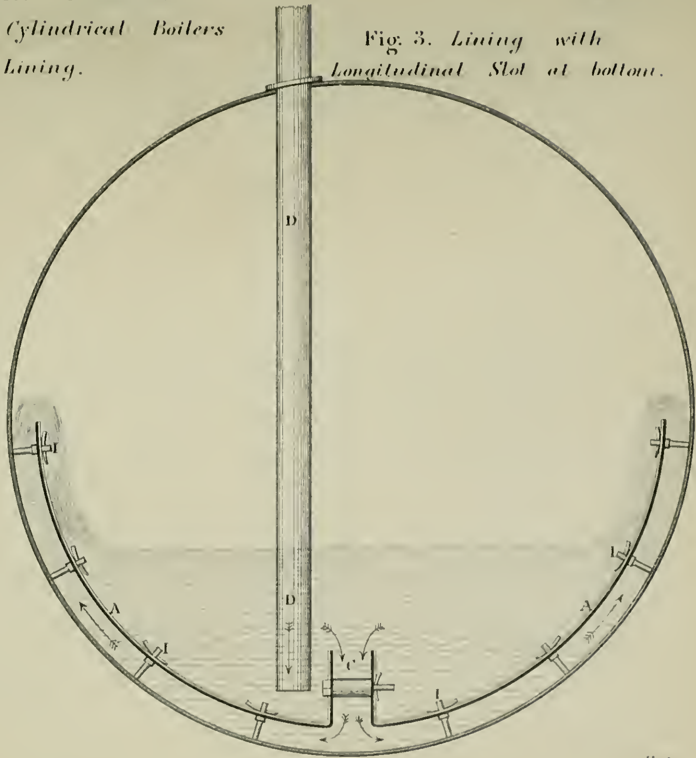


Fig. 3. *Lining with Longitudinal Slot at bottom.*



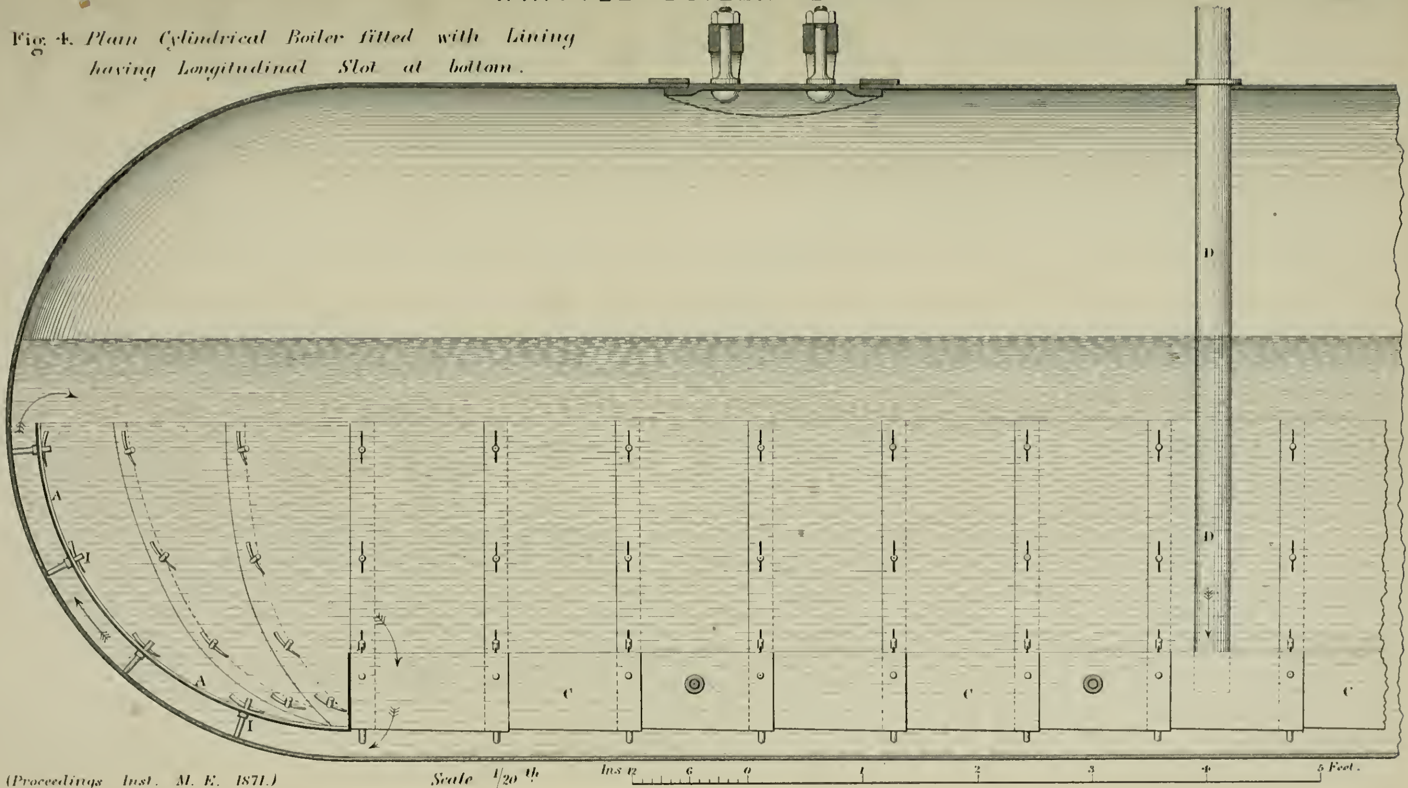
Scale 1/20th

Ins. 12 6 0 1 2 3 4 5 Feet.

(Proceedings Inst. M. E. 1871.)

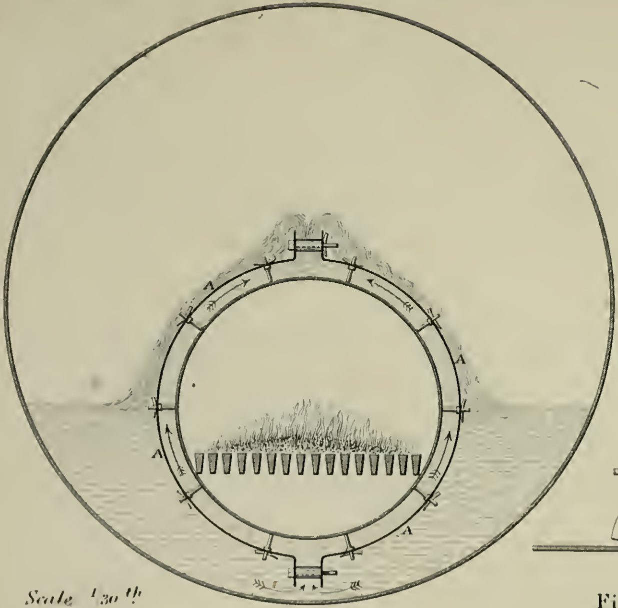
WHITTLE BOILER LINING.

Fig. 4. *Plain Cylindrical Boiler fitted with Lining having Longitudinal Slot at bottom.*



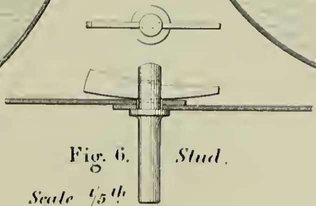
WHITTLE BOILER LINING.

Fig. 5. Transverse Section of Cornish Boiler with Lining round the internal flue.



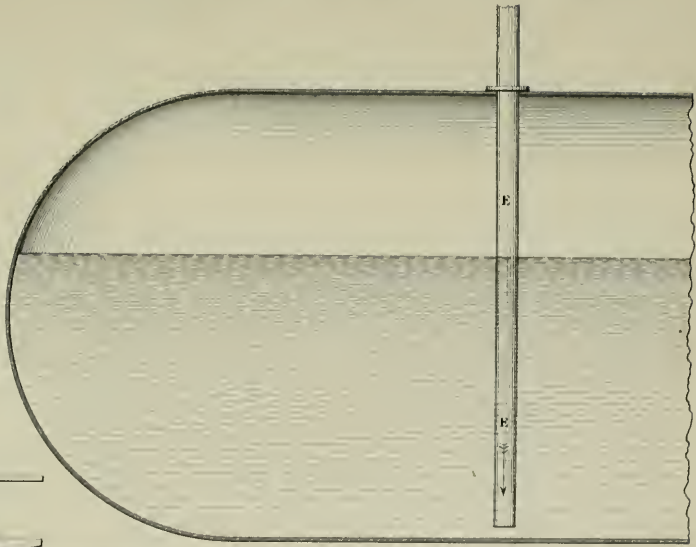
Scale 1/30th

Fig. 6. Stud.



Scale 1/5th

Fig. 7. Ordinary Cylindrical Boiler.

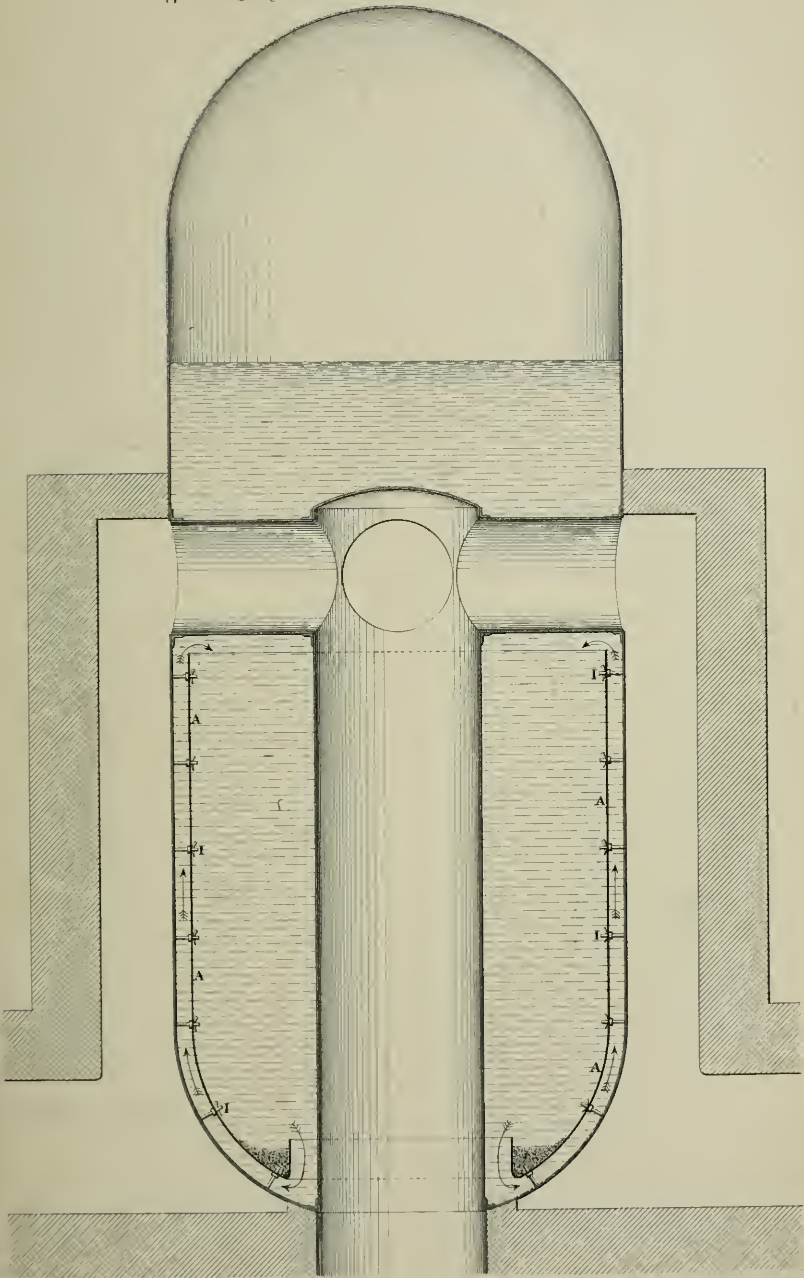


Scale 1/30th

Ins. 12 6 0 1 2 3 4 5 Feet.

(Proceedings Inst. M. E. 1871.)

Fig. 8. *Upright Boiler fitted with Lining.*



Scale 1/40th.

0 1 2 3 4 5 6 7 8 9 10 Feet.

1/30

PROCEEDINGS.

26 January, 1871.

The Twenty-fourth Anniversary Meeting of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 26th January, 1871; John Ramsbottom, Esq., President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The following Annual Report of the Council was then read:—

ANNUAL REPORT OF THE COUNCIL.

1871.

The Council on this occasion of the Twenty-fourth Anniversary present to the Members the annual statement of the position of the Institution and the progress during the past year.

The Financial statement of the affairs of the Institution for the year is satisfactory, showing that the balance on 31st December 1870 was £6309 12*s.* 11*d.*, after payment of the accounts due to that date. Of this amount the sum of £4500 is invested in London and North Western Railway 4 per cent. Debentures; and a further sum of £1500 will now be invested. The Finance Committee have examined and checked the receipts and payments of the Institution for last year 1870, and report that the following Balance Sheet rendered by the Treasurer is correct. (*See Balance Sheet appended.*)

The total number of Members of all classes in the Institution for last year is 862, of whom 4 are Honorary Life Members, 33 are

Associates, and 24 are Graduates; 55 of the whole are resident in various foreign countries.

The following deceases of Members of the Institution have occurred during the past year 1870:—

GEORGE BELL.	Bolton.
WILLIAM CHADWICK.	Leeds.
ZERAH COLBURN.	London.
JAMES COPE.	Dudley.
THOMAS WILKS LORD.	Leeds.
JOSEPH PITTS.	Stanningley.
JOHN PLAYER.	Philadelphia.
THOMAS STUBBS,	Crewe.
WILLIAM TOWNSEND.	Coventry.
WILLIAM WHITEHEAD.	Sheffield.

The following Donations to the Library of the Institution have been received during the past year, and the Council have the pleasure of expressing their thanks to the Donors for these additions to the library. They trust the Members generally will promote the formation of a good collection of Engineering Books, Drawings, and Models or Specimens of interest in the Institution, for the purpose of reference by the Members personally or by correspondence; and with this view Members are requested to present copies of their Works to the Library of the Institution.

LIST OF DONATIONS TO THE LIBRARY.

Report on Artillery, by Lt.-Colonel Owen; from the author.

On the "Derivation" of Elongated Projectiles fired from Rifled Ordnance, by Lt.-Colonel Owen; from the author.

Experiments on the Mechanical and other Properties of Steel, by a Committee of Civil Engineers; from the Committee.

On the Scantlings of Iron Steam Vessels, by John Price; from the author.

Report on the Sea-Lighting of the Entrance to the Yang-Tsze River, China, by David M. Henderson; from the author.

On Lighthouse Apparatus and Lanterns, by David M. Henderson; from the author.

On Working Coal by Long-Wall, by George Fowler; from the author.

Papers on the Theory and Practice of Coal Mining, by George Fowler; from the author.

The Principles of Hydrostatics, by Thomas Webster; from the author.

On the Allen Engine and Porter Governor; from Mr. Charles T. Porter.

On Light Railways in Sweden, by Christer P. Sandberg; from the author.

On the Economy of Road Maintenance by Steam Rolling, by F. A. Paget; from the author.

The Education and Status of Civil Engineers; from the Institution of Civil Engineers.

The Patent Laws, by Theophilus Aston; from Mr. William W. Hulse.

On Patents for Inventions, by St. John V. Day; from the author.

Proceedings of the Institution of Civil Engineers; from the Institution.

Proceedings of the French Institution of Civil Engineers; from the Institution.

Report of the British Association for the Advancement of Science; from the Association.

Transactions of the North of England Institute of Mining Engineers; from the Institute.

Proceedings of the South Wales Institute of Engineers; from the Institute.

Transactions of the Institution of Engineers in Scotland; from the Institution.

Transactions of the Iron and Steel Institute; from the Institute.

Proceedings of the Royal Artillery Institution; from the Institution.

Transactions of the Royal Scottish Society of Arts; from the Society.

Transactions of the Institution of Surveyors; from the Institution.

Proceedings of the Royal Institution of Great Britain; from the Institution.

Journal of the Royal United Service Institution; from the Institution.

Professional Papers of the Corps of Royal Engineers; from the Royal Engineer Establishment.

Professional Papers on Indian Engineering; from the Royal Engineer Establishment.

Lectures at the Royal Engineer Establishment; from the Establishment.

Report of the Royal Cornwall Polytechnic Society; from the Society.

Journal of the Hannover Architect and Engineer's Society; from the Society.

Journal of the French Society for the Encouragement of National Industry; from the Society.

Journal of the Saxon Society of Engineers; from the Society.

Journal of the Norwegian Polytechnic Society; from the Society.

Transactions of the American Society of Civil Engineers and Architects; from the Society.

Report of the Smithsonian Institution for 1868; from the Institution.

The Indians of Cape Flattery, by James G. Swan; from the Smithsonian Institution.

Reports of the United States Treasury Department; from the Smithsonian Institution.

Report of the Bombay Mechanics' Institute; from the Institute.

Reports of the Manchester Association for the Prevention of Steam Boiler Explosions; from Mr. Lavington E. Fletcher.

Report of the Manchester Boiler Insurance Company; from Mr. Robert B. Longridge.

Reports of the Midland Steam Boiler Association; from Mr. Edward B. Marten.

Records of Steam Boiler Explosions, by Edward B. Marten; from the author.

United States Patent Office Report for 1867; from the Commissioner.

Journal of the Society of Arts; from the Society.

The Engineer; from the Editor.

Engineering; from the Editor.

The Mechanics' Magazine; from the Editor.

The Artizan Journal; from the Editor.

The Practical Mechanic's Journal; from the Editor.

The Mining Journal; from the Editor.

The Railway Record; from the Editor.

The Iron and Coal Trades Review; from the Editor.

The Papers brought before the meetings during the past year have possessed much practical interest; and form, with the discussions that took place upon them, a valuable addition to the Proceedings of the Institution. The Council request the aid and co-operation of the Members in carrying out the objects of the Institution and maintaining its advanced position, by contributing Papers on Engineering subjects that have come under their observation, and communicating the particulars and results of executed works and practical experiments that may be serviceable and interesting to the Members; and they invite communications upon the subjects in the list appended and other subjects advantageous to the Institution.

The following Papers have been read at the Meetings during the past year:—

On Le Chatelier's plan of using Counter-pressure Steam as a Break in Locomotive Engines; by Mr. C. William Siemens.

On the Further Economy of Fuel in Blast Furnaces, derivable from the High Temperature of Blast obtained with Cowper's improved Regenerative Stoves at Ormesby, and from Increased Capacity of Furnace, &c.; by Mr. Charles Cochrane.

On a Steam Road Roller; by Mr. W. F. Batho and Mr. T. Aveling.

On Self-Acting Machinery for Knitting Hosiery by Power; by Mr. Arthur Paget.

On the Mode of Working and the Mechanical Appliances employed in the Midland Coalfield; by Mr. George Fowler.

On the Conclusions derived from the experience of recent Steam Boiler Explosions; by Mr. Edward B. Marten.

Description of a Self-acting Safety and Fire-Extinguishing Valve for Steam Boilers; by Mr. George D. Hughes.

On the Warsop Aero-Steam Engine; by Mr. Richard Eaton.

Description of a Wire-Rope Bridge at the Landore Steel Works for conveying materials across a navigable stream; by Mr. William Hackney.

The Annual Meeting of the Institution last summer was held in Nottingham, and the Council have particular pleasure in expressing their special thanks to Mr. Hawksley, Vice-President, and the Local members of the Institution, for the excellent and cordial reception given to the Members on the occasion; and also their thanks to the proprietors of the works that were so liberally thrown open for the inspection of the Members; and to the railway authorities for the special arrangements granted for the excursions. The Council desire particularly to acknowledge the valuable opportunity afforded to the Members for visiting the numerous Lace, Hosiery, and Machine Works in Nottingham, the Iron Works and Collieries in the neighbourhood, the Derby Locomotive Works, Burton Breweries, and Lincoln Agricultural Engine and Implement Works. They have great satisfaction in referring to the advantages arising from these Annual Meetings of the Institution in different localities, from the facilities thereby afforded for the personal communication of the Members in different districts, and from the opportunities of visiting the important Engineering Works so liberally thrown open on those occasions.

The President, Vice-Presidents, and five of the Members of the Council in rotation, go out of office this day, according to the rules of the Institution; and the ballot which is taken at the present Meeting will show the election of the Officers and Council for the ensuing year.

SUBJECTS FOR PAPERS.

Steam Engine Boilers, particulars of construction—form and extent of heating surface—relative value of radiant surface and flue surface in effect and economy—cost—consumption of fuel—evaporation of water—pressure of steam—density and heat of steam—superheated steam, simple or mixed with common steam—combined air and steam—pressure gauges—safety valves—water gauges—explosion of boilers, and means of prevention—effects of heat on the metal of boilers, low-pressure and high-pressure—steel boilers—cast-iron boilers—welded boilers—incrustation of boilers, and means of prevention—corrosion of boilers, and means of prevention—effects of surface condensers on the metal of boilers—evaporative power and economy of different kinds of fuel, coal, wood, charcoal, peat, patent coal, and coke—mechanical firing, moveable grates, and smoke-consuming apparatus, facts to show the best plan, and results of working—plans for heating feed-water—mode of feeding—use of injector—circulation of water.

Steam Engines—expansive force of steam, and best means of using it—power obtained by various plans—comparison of double and single cylinder engines—combined engines—compound cylinder engines—comparative advantages of direct-acting and beam engines—engines for manufacturing purposes—horizontal and vertical—condensing and non-condensing—injection and surface condensers—air pumps—governors—valves—bearings, &c.—improved expansion gear—indicator diagrams from engines, with details of useful effect, consumption of fuel, &c.—contributions of indicator diagrams for reference in the Institution.

Pumping Engines, particulars of various constructions—Cornish engines, beam engines with crank and flywheel, direct-acting engines with and without flywheel—size of steam cylinder and degree of expansion—number and size of pumps, and strokes per minute—speed of piston—pressure upon pump—effective horse power and duty—comparison of double-acting and single-acting pumping engines—construction of pumps—plunger pumps—bucket pumps—particular details of different valves—india-rubber valves, durability and results of working—diagrams of lift of valves—application of pumps—fen-draining engines—comparative advantages of scoop wheels and centrifugal pumps, lifting trough, &c.—sewage pumping engines—details of pit work of pumping engines in mines.

Blast Engines, best kind of engine—size of steam cylinder, strokes per minute, and horse power—details of boilers—size of blowing cylinder, and strokes per minute—pressure of blast, and means of regulation—construction of valves—improvements in blast cylinders—rotary blowing machines—indicator diagrams from air main and steam cylinder.

Marine Engines, power of engines in proportion to tonnage—different constructions of engines, double-cylinder engines, trunk engines—three-cylinder engines—use of steam jackets—dynamical effect compared with indicator diagrams—comparative economy and durability of different boilers, tubular boilers, flat-flue boilers, &c.—brine pumps, and means of preventing deposit—salinometers—weight of machinery and boilers—kind of paddle wheels—speed obtained in British war steamers, in British merchant steamers, and in Foreign ditto, with particulars of the construction of engines with paddle wheels, &c.—screw propellers, particulars of different kinds, improvements in form and position, number of arms, material, means for unshipping, bearings, horse power applied, speed obtained, section of vessel—reaction propellers—governors and storm governors.

Rotary Engines, particulars of construction and practical application—details of results of working.

Locomotive Engines, particulars of construction, details of experiments, and results of working—consumption of fuel—relative value and evaporative duty of coke and coal—consumption of smoke—use of wood and construction of spark arresters—heating surface, length and diameter of tubes—material of tubes—experiments on size of tubes and blast pipe—construction of pistons, valves, expansion gear, &c.—balanced slide-valves—indicator diagrams—expenses of working and repairs—means of supplying water to tenders—locomotives for steep gradients and sharp curves—distribution of weight on wheels.

Agricultural Engines, details of construction and results of working—duty obtained—application of machinery and steam power to agricultural purposes—barn machinery—field implements—traction engines, particulars of performance and cost of work done—steam road rollers, particulars and results.

Hot-Air Engines—engines worked by gas, or explosive compounds—electro-magnetic engines—particulars and results.

Hydraulic Engines, particulars of application and working—pressure of water—construction and arrangement of valves, relief valves—construction of joints—hydraulic rams.

Water Wheels, particulars of construction and dimensions—form and depth of buckets—head of water, velocity, percentage of power obtained—

turbines, construction and practical application, power obtained, comparative effect and economy—transmission of power to distant points.

WIND MILLS, particulars of construction—number of sails, surface and form of sails—velocity, and power obtained—average number of days' work per annum.

CORN MILLS, particulars of improvements—power employed—application of steam power—results of working with an air blast and ring stones—crushing by rolls before grinding—advantages of regularity of motion—stone dressing machinery.

SUGAR MILLS, particulars of construction and working—results of application of the hydraulic press in place of rolls—application of steam and water for extracting the last portion of saccharine matter—construction and working of evaporating pans.

OIL MILLS, facts relating to construction and working, by stampers, by screw presses, and by hydraulic presses—particulars of crushing rollers and edge stones.

COTTON MILLS, information respecting the construction and arrangement of the machinery—power employed, and application of power—cotton presses, mode of construction and working, power employed—improvements in spinning, carding, and winding machinery, &c.

CALICO-PRINTING AND BLEACHING MACHINERY, particulars of improvements.

WOOL MACHINERY, carding, combing, roving, spinning, &c.

FLAX MACHINERY, manufacture of flax, china grass, and other fibrous materials, both in the natural length of staple and when cut.

WEAVING MACHINERY, for manufacture of different materials—improvements in looms, &c.

KNITTING MACHINERY, worked by hand or by power—particulars of improvements.

ROPE-MAKING MACHINERY—hemp and wire ropes, comparative strength, durability, and cost—steel wire ropes—transmission of power by ropes, percentage of loss, distance, wear of ropes, &c.

SAW MILLS, particulars of construction—mode of driving—power employed—particulars of work done—best speeds for vertical and circular saws—form of saw teeth—saw mills for cutting ship timbers—veneer saws—endless band saws.

WOOD-WORKING MACHINES, morticing, dovetailing, planing, rounding, and surfacing—copying machinery.

GLASS MACHINERY—manufacture of plate and sheet glass—construction of heating furnaces, annealing kilns, &c.—grinding and polishing machinery.

LATHES, PLANING, BORING, DRILLING, SLOTTING, AND SHAPING MACHINES, &c., particulars of improvements—description of new self-acting tools—engineers' tools—files and file-cutting machinery.

ROLLING MILLS, improvements in machinery for making iron and steel—mode of applying power—use of steam hammers—piling of iron—plates—fancy sections—arrangement and speed of rolls—length of bar rolled—manufacture of rolled girders—rolling of armour plates—reversing rolls.

STEAM HAMMERS, improvements in construction and application—friction hammers—air hammers.

RIVETTING, PUNCHING, AND SHEARING MACHINES, worked by steam or hydraulic pressure—direct-acting and lever machines—portable machines—comparative strength of drilled and punched plates—rivet-making machines.

STAMPING AND COINING MACHINERY, particulars of improvements, &c.

LOCKS, and lock-making machinery—iron safes.

PAPER-MAKING AND PAPER-CUTTING MACHINES, new materials and results.

PRINTING MACHINES, particulars of improvements, &c.—machines for printing from engraved surfaces—type composing and distributing machines.

WATER PUMPS, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

AIR PUMPS, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

HYDRAULIC PRESSES, facts relating to the best construction, means of working, and application—economical limit of pressure.

ROTARY AND CENTRIFUGAL PUMPS, ditto ditto ditto.

FIRE ENGINES, hand and steam, ditto ditto ditto.

SLUICES AND SLUICE COCKS, worked by hand or hydraulic power, ditto.

CRANES—steam, hydraulic, and pneumatic cranes—travelling cranes.

LIFTS for raising railway wagons—hoists for warehouses—safety apparatus.

TOOTHED WHEELS, best construction and form of teeth—results of working—strength of iron and wood teeth—moulding by machinery.

DRIVING BELTS AND STRAPS, best make and material, leather, gutta-percha, vulcanised india-rubber, rope, wire, chain, &c.—comparative durability, and results of working—power communicated by certain sizes—frictional gearing, construction and driving power obtained—friction clutches—shafting and couplings.

DYNAMOMETERS, construction, application, and results of working.

DECIMAL MEASUREMENT—application of decimal system of measurement to mechanical engineering work, drawing and construction of machinery, manufactures, &c.—construction of measuring instruments, gauges, &c.

STRENGTH OF MATERIALS, facts relating to experiments, and general details of the proof of girders, &c.—girders of cast and wrought iron, particulars of different constructions, and experiments on them—rolled girders—best forms and proportions of girders for different purposes—best mixture of metal—mixtures of wrought iron with cast.

Durability of Timber of various kinds—best plans for seasoning and preserving timber and cordage—results of various processes—comparative durability of timber in different situations—experiments on actual strength of timber.

Corrosion of Metals by salt and fresh water, and by the atmosphere, &c.—facts relating to corrosion, and best means of prevention—means of keeping ships' bottoms clean—galvanic action, nature and preventives.

Alloys of Metals, facts relating to different alloys.

Friction of Various Bodies, facts relating to friction under ordinary circumstances—facts on increase of friction by reduction of surface in contact—friction of iron, brass, copper, tin, wood, &c.—proportion of weight to rubbing surface—best forms of journals, and construction of axleboxes—wood bearings—water axleboxes—lubrication, best materials, means of application, and results of practical trials—best plans for oil tests—friction breaks.

Iron Roofs, particulars of construction for different purposes—durability in various climates and situations—comparative cost, weight, and durability—roofs for slips of cast-iron, wrought-iron, timber, &c.—best construction, form, and materials—details of large roofs, and cost.

Fire-proof Buildings, particulars of construction—most efficient plan—results of trials.

Chimney Stacks of large size—particulars, form, mode of building, cheapest construction, &c.—force of draught, and temperature of current.

Bricks, manufacture, durability, and strength—hollow bricks, fire bricks, and fire clay—perforated bricks, cost of manufacture, and advantages—dry-clay bricks—machines for brick-making—burning of bricks.

Gas Works, best form, size, and material for retorts—construction of retort ovens—quantity and quality of gas from different coals—oil gas, cheapest mode of making—water gas, &c.—improvements in purifiers, condensers, and gasholders—wet and dry gas meters—self-regulating meters—pressure of gas, gas exhauster—gas pipes, strength and durability, and construction of joints—proportionate diameter and length of gas mains, and velocity of the passage of gas—experiments on ditto, and on the friction of gas in mains, and loss of pressure—lighting railway trains with gas.

Water Works, facts relating to water works—application of power, and economy of working—proportionate diameter and length of pipes—experiments on the discharge of water from pipes, and friction through pipes—strength and durability of pipes and construction of joints—penetration of frost in different climates—relative advantages of stand pipes and air vessels—sluices and self-acting valves—machinery for working sluices—water meters, construction and working.

WELL SINKING AND ARTESIAN WELLS, facts relating to—boring tools. construction and mode of using.

TUNNELLING MACHINES, particulars of construction, and results of working.

COFFERDAMS AND PILING, facts relating to construction—cast-iron sheet piling.

PIERS, fixed and floating, and pontoons, ditto ditto.

PILE DRIVING APPARATUS, particulars of improvements—use of steam power—particulars of working—weight of ram and height of fall, total number of blows required—vacuum piles—compressed air system—screw piles—pile shoes.

DREDGING MACHINES, particulars of improvements—application of dredging machines—power required and work done.

DIVING BELLS AND DIVING DRESSES, facts relating to the best construction.

LIGHTHOUSES, cast-iron and wrought-iron. ditto ditto.

SHIPS, iron and wood—details of construction—lines, tonnage, cost per ton—water ballast—steel masts and yards, and wire-rope rigging—comparative strength and advantage of iron and wood ships—arrangements for docking and repairing ships—steering gear—application of steam power to steering.

GUNS, cast-iron, wrought-iron, and steel—manufacture and proof—rifling—manufacture of shot and shells.

SMALL ARMS, machinery for manufacture of rifles and cartridges, &c.—breech-loading mechanism.

MINING OPERATIONS, facts relating to mining—modes of working and proportionate yield—coal-cutting machines—means of ventilating mines—use of ventilating machinery—safety lamps—lighting mines by gas—drainage of mines—sinking pits—mode of raising materials—safety guides—winding machinery—underground conveyance—stone-breaking machines—mode of breaking, pulverising, and sifting various descriptions of ores.

BLASTING, facts relating to blasting under water, and blasting generally—use of gun-cotton, &c.—effects produced by large and small charges of powder—arrangement of charges.

BLAST FURNACES, shape and size—consumption of fuel—yield and quality of metal—pressure of blast—economy of working—improvements in manufacture of iron—comparative results of hot and cold blast—increased temperature of blast—construction and working of hot-blast stoves—pyrometers—construction of tuyeres—means and results of application of waste gas from close-topped and open-topped furnaces—preparation of materials for furnace and mode of charging.

PUDDLING FURNACES, best forms and construction—worked with coal, charcoal, &c.—application of machinery to puddling.

HEATING FURNACES, best construction—consumption of fuel, and heat obtained.

CUPOLAS, construction and proportions—improvements in means of blowing—results of working, and economy of fuel.

CONVERTING FURNACES, construction of furnaces—manufacture of steel—casehardening, &c.—converting materials employed.

SMITHS' FORGES, best construction—size and material—power of blast—hot blast, &c.—construction of tuyeres.

SMITHS' FANS AND FANS generally, best construction, form of blades, &c.—facts relating to power employed and percentage of effect produced—pressure and quantity of air discharged—size and construction of air mains—mechanical ventilation and warming of public buildings.

COKE AND CHARCOAL, particulars of the best mode of making, and construction of ovens, &c.—open coking, mixtures of coal-slack and other materials—evaporative power of different varieties—peat, manufacture of compressed peat.

RAILWAYS, construction of permanent way—section of rails, and mode of manufacture—mode of testing rails—experiments on rails, deflection, deterioration, and comparative durability—material and form of sleepers, size, and distances—improvements in chairs, keys, and joint fastenings—permanent way for hot climates.

SWITCHES AND CROSSINGS, particulars of improvements, and results of working.

TURNTABLES, particulars of various constructions and improvements—engine turntables.

SIGNALS for stations and trains, and self-acting signals.

ELECTRIC TELEGRAPHS, improvements in construction and insulation—coating of wires—underground and submarine cables—mode of laying, and machinery employed.

RAILWAY CARRIAGES AND WAGONS, details of construction—proportion of dead weight.

BREAKS for carriages and wagons, best construction—self-acting breaks—continuous breaks—steam breaks.

BUFFERS for carriages, &c., and station buffers—different constructions and materials.

COUPLINGS for carriages and wagons—safety couplings.

SPRINGS for carriages, &c.—buffing, bearing, and draw springs—range, and deflection per ton—particulars of different constructions and materials, and results of working.

RAILWAY WHEELS, wrought-iron, cast-iron, and wood—particulars of different constructions, and results of working—comparative expense and durability—wrought-iron and steel tyres, comparative economy and results of working—mode of fixing tyres—manufacture of weldless tyres, and solid wrought-iron wheels.

RAILWAY AXLES, best description, form, material, and mode of manufacture.

PREPARATION OF PAPERS.

The Papers to be written in the third person, on foolscap paper, on one side only of each page, leaving a clear margin of an inch width on the left side. In the subjects of the papers, extracts from printed publications and questions of patent right or priority of invention are not admissible.

The Diagrams to be on a large scale and strongly coloured. so as to be clearly visible to the meeting at the time of reading the paper. Enlarged details to be added for the illustration of any particular portions, drawn full size or magnified, with the different parts strongly coloured in distinctive colours. Several explanatory diagrams drawn roughly to a large scale in dark pencil lines and strongly coloured are preferable to a few small-scale finished drawings. The scale of each diagram to be marked upon it.

INSTITUTION OF MECHANICAL ENGINEERS.

BALANCE SHEET.

For the year ending 31st December 1870.

Cr.		£ s. d.
By Balance 31st Dec. 1869; Invested	4500 0 0	
In Bank	1018 15 9	5518 15 9
,, Subscriptions from 61 Members in arrear . .		183 0 0
,, do. from 4 Associates in arrear		12 0 0
,, do. from 1 Graduate in arrear		2 0 0
,, do. from 676 Members for 1870		2028 0 0
,, do. from 27 Associates for 1870		81 0 0
,, do. from 20 Graduates for 1870		40 0 0
,, do. from 9 Members in advance for 1871 .		27 0 0
,, do. from 3 Life Members		90 0 0
,, Entrance Fees from 56 New Members . . .		112 0 0
,, do. from 2 New Associates		4 0 0
,, do. from 4 New Graduates		4 0 0
,, Sale of Extra Reports		22 5 0
,, Interest; From Bank	37 8 1	
On £4500 invested at 4 per cent., one year, from 15 July 69 to 15 July 70	180 0 0	217 8 1
		£8341 8 10

Dr.		£ s. d.
To Printing and Engraving Reports of Proceedings	634 15 6	
Less Authors' copies of Papers, repaid	43 13 0	591 2 6
,, Stationery, Binding, Printing of Circulars, &c. .		97 2 8
,, Office Expenses, Clerks, and Petty Disbursements		111 18 6
,, Coals, Gas, and Water		17 7 11
,, Expenses of Meetings		53 2 9
,, Fittings and Repairs		23 6 7
,, Travelling Expenses		47 15 10
,, Parcels		3 14 8
,, Postages		107 2 6
,, Salaries		859 17 0
,, Insurance		2 10 0
,, Rent and Taxes		116 15 0
Balance 31st Dec. 1870; Invested	4500 0 0	
In Bank	1809 12 11	6309 12 11
		£8341 8 10

(Signed) SAMPSON LLOYD, CHARLES COCHRANE, WALTER MAY, Finance Committee.

26th January, 1871.

MEMOIRS

OF MEMBERS DECEASED IN 1870.

George Bell was born in 1808, and served his time with Messrs. Fairbairn and Lilley in Manchester; he afterwards worked at Messrs. Fawcett's in Liverpool, and left them in 1838 to take the position of foreman over the millwrights at the Soho Iron Works, Bolton, belonging to Messrs. Benjamin Hick and Son. This office he filled with such ability and success that about two years ago he was admitted into partnership by the firm; and he continued to occupy that position up to the time of his death, which took place on the 26th November 1870, when both he and his wife were killed in the lamentable railway accident at Harrow. He became a Member of the Institution in 1867.

William Chadwick was born at Leeds on the 10th June 1810. In 1833 he was engaged by the Low Moor Iron Company as their agent in Leeds and the district; and continued so until 1843, when he took up the dyeing business of his brother. This business he afterwards relinquished, and again entered the iron trade; and he represented the Monk Bridge Iron Company at the time of his death, which took place suddenly on the 10th July 1870 at the age of sixty. He became an Associate of the Institution in 1866.

Zerah Colburn was born at Saratoga, New York, in 1832, and began life on a farm in New Hampshire. His professional career commenced on the Concord Railway at Boston, and he was afterwards engaged in the locomotive works of Mr. Souther at Boston, and for a short time superintended the New Jersey Locomotive Works at Patterson. He subsequently entered upon professional literature, and became connected with railway journals

in New York, and in 1857 visited Europe for the purpose of examining into railway construction and locomotive working. In 1858 he came to London and became ultimately editor of "The Engineer"; he returned for a time to America, and then settled again in London, where in 1866 he started the journal "Engineering," with which he was connected up to nearly the time of his death. He was distinguished by the activity, vigour, and intelligence of his numerous professional writings. He died at Belmont, Massachusetts, on the 26th April 1870 at the age of thirty-seven, his mental powers having rapidly given way towards the last. He became a Member of the Institution in 1864.

James Cope was born at Milton, near Stoke-upon-Trent, on the 14th September 1818. He learnt land-surveying with his brother, Mr. W. S. Cope of North Staffordshire, and was subsequently engaged under Mr. J. T. Woodhouse of Derby. He afterwards went to South Staffordshire, where he held the important position of mining engineer under the New British Iron Co., Messrs. Mathews and Bond, Messrs. John Dawes and Sons, and others; and his extensive practical knowledge caused him to be frequently consulted in cases of difficulty in reference to mining. He died at Bromley, Pensnett, on the 22nd January 1870, in the fifty-second year of his age. He became a Member of the Institution in 1860.

Thomas Wilks Lord was born in 1809 at Halliwell, Bolton, and from 1823 to 1835 was with his father, Mr. John Lord, cotton spinner, of that place. About 1836 he commenced business as a maker of flax, tow, and hemp machinery at the Albion Foundry, Leeds, and continued more or less connected with that business up to the time of his death, which took place at Harrogate on the 17th July 1870 at the age of sixty-one. He became a Member of the Institution in 1859.

Joseph Pitts was born in 1812 at Dudley Hill, near Bradford, Yorkshire, and in 1834 entered the service of Messrs. Butler and Taylor, ironfounders, Stanningley, near Leeds. On the death of

Mr. Taylor in 1838 he became traveller for the surviving partner, the late Mr. Joseph Butler, who carried on the business until 1851, when it was transferred to his son Mr. John Butler, and Mr. Pitts; and the firm of Messrs. Butler and Pitts, of Stanningley Iron Works, attained a prominent position as engineers and iron bridge builders, a large number of bridges having been constructed and erected by them, both in this country and abroad. Mr. Pitts died at Stanningley on the 17th March 1870 at the age of fifty-eight; he became a Member of the Institution in 1859.

John Player was born at Elberton in Gloucestershire in 1808, and was educated at a private school in Wiltshire. His first work as an engineer was the erection of the Gwendraeth Iron Works in Carmarthenshire, of which he was appointed manager in 1838. About this time he turned his attention to the introduction of anthracite coal into more general use as a fuel for blast furnaces and steam boilers; and the furnace at the Gwendraeth Works was built in accordance with his plan for making iron with anthracite coal and cold blast. He also designed a steam boiler and blacksmith's forge for using the same fuel, both of which were in successful operation at the Gwendraeth Works. In 1839 a steamer called the "Anthracite" was built and fitted with boilers on the same plan, and ran for some time on the Thames below London Bridge, attracting much notice in consequence of the absence of smoke. In 1841 he was engaged to erect an ironworks at Hachenberg in the duchy of Nassau. In 1846 he returned to England, and was engaged soon afterwards for a short time at the Bryn Amman Iron Works in Carmarthenshire. Subsequently he went to America and visited the ironworks in Pennsylvania; and on his return he was engaged in building blast furnaces in the Middlesbrough district. In 1866 he introduced some improvements in hot-blast stoves, in connection with which he was induced to go again to America, where the improved stoves have been very extensively adopted. He settled at Philadelphia in 1868, and at the time of his death was engaged in erecting iron furnaces in different parts of the United States. His last invention was for the manufacture of a substance which he termed "mineral

wool" from iron slag; it has the appearance of wool, and being incombustible and a non-conductor, is intended for casing high-pressure steam pipes and locomotive boilers, instead of hair felt. He died at Philadelphia of typhoid fever after a few days' illness on the 11th March 1870 at the age of sixty-two. He became a Member of the Institution in 1862.

Thomas Stubbs was born at Carlisle in 1836, and in 1852 entered the service of the London and North Western Railway as a draughtsman in the locomotive department at Longsight, Manchester; in 1857 he was transferred to the Crewe Works, and in 1861 was placed in charge of the drawing office; and in 1866 he was appointed manager of the works, under Mr. Ramsbottom, and filled that position with great satisfaction up to the time of his death, which took place at Crewe, after an illness of three weeks, on the 17th September 1870, in the thirty-fourth year of his age. He was elected a Member of the Institution in 1870.

William Townsend was born at Coventry in 1838, and was there apprenticed to his father's business, in which he had to do with a good deal of machinery of all kinds, and had many facilities for acquiring a practical knowledge of mechanical engineering. In 1868, while travelling in Spain, he thought that the application of Mr. Hodgson's wire-tramway system would be very valuable in such a country, with bad roads and few railways; and relinquishing his connection with the business at Coventry, he succeeded in making some contracts for the construction of wire tramways in Spain, which however were not carried out at the time, owing to the unsettled state of the country. He then proceeded to Austria with the same object, and successfully erected at Pesth a line of wire tramway for conveying coal from the barges in the Danube to a store at the side of the river. On a second visit to Austria early in 1870, for the purpose of carrying out further work of the same description, he was struck down by typhus fever at Vienna, and died there on the 19th April at the age of thirty-two. He became a Member of the Institution in 1863.

William Whitehead, born near Rotherham in 1829, was brought up as a file manufacturer, and carried on that business for some years as a partner in the firm of Messrs. John Martin and Co., steel and file manufacturers, Sheffield. In 1858 he joined Messrs. Naylor Vickers and Co., Sheffield, and was subsequently admitted a partner in that firm; on its formation into a company in 1867 he was appointed one of the managing directors, and held the office to the time of his death, which took place suddenly on the 20th February 1870. He became an Associate of the Institution in 1862, and a Member in 1868.

The PRESIDENT said he was sure the Members would concur with him in feeling much gratification at finding that the Council were able again to present so satisfactory a report of the prosperous condition of the Institution for the past year. He wished to take this opportunity of expressing his own great regret that he had been prevented by severe illness from being present at the meeting in Nottingham in the summer, which had been a highly interesting and successful one, justifying the choice the Council had made of that locality for the meeting. He had great pleasure in moving that the Report of the Council be received and adopted, which was passed.

The President announced that the Ballot Lists had been duly opened, and the following Officers and Members of Council were found to be elected for the ensuing year:—

PRESIDENT.

JOHN RAMSBOTTOM, ...	Crewe.

VICE-PRESIDENTS.

FREDERICK J. BRAMWELL, . .	London.
THOMAS HAWKSLEY, . . .	London.
SAMPSON LLOYD, ...	Wednesbury.
WILLIAM MENELAUS, . . .	Merthyr Tydvil.
JOHN ROBINSON, ...	Manchester.
C. WILLIAM SIEMENS, . . .	London.

COUNCIL.

HENRY BESSEMER, ...	London.
WILLIAM CLAY, ...	Birkenhead.
CHARLES P. STEWART, . . .	Manchester.
FRANCIS W. WEBB, . . .	Bolton.
PERCY G. B. WESTMACOTT, . .	Newcastle-on-Tyne.

PAST-PRESIDENTS.

Ex-officio permanent Members of Council.

SIR WILLIAM G. ARMSTRONG, C.B., .	Newcastle-on-Tyne.
SIR WILLIAM FAIRBAIRN, BART., .	Manchester.
JAMES KENNEDY, ...	Liverpool.
ROBERT NAPIER, ...	Glasgow.
JOHN PENN, ...	London.
SIR JOSEPH WHITWORTH, BART., .	Manchester.

COUNCIL.

Members of Council remaining in office.

Charles Edwards Amos, . . .	London.
John Anderson, ...	Woolwich.
I. Lowthian Bell, ...	Newcastle-on-Tyne.
Charles Cochrane, . . .	Dudley.
John Fernie, ...	Ventnor, Isle of Wight.
Edgar Gilkes, ...	Middlesbrough.
Thomas Greenwood, . . .	Leeds.
George Harrison, . . .	Birkenhead.
Frederick W. Kitson, . . .	Leeds.
Walter May, ...	Birmingham.

TREASURER.

Henry Edmunds, ...	Birmingham.

SECRETARY.

William P. Marshall, . .	Birmingham.

ASSISTANT SECRETARY.

Alfred Bache, ...	Birmingham.

The following New Members were also elected :—

MEMBERS.

Howard Aston Allport, . .	Derby.
Edgar James Edwards, . .	Alfreton.
Alfred Hargreaves Gowenlock, .	Calcutta.
Druitt Halpin, ...	Lahore, India.
Peter Soames, ...	London.

The following paper was then read :—

ON THE MECHANICAL VENTILATION OF THE LIVERPOOL PASSENGER TUNNEL ON THE LONDON AND NORTH WESTERN RAILWAY.

By JOHN RAMSBOTTOM, Esq., President.

The London and North Western Railway in starting from Liverpool passes through a Tunnel 2025 yards in length and of a mean sectional area of 430 square feet, the line rising at an average inclination through the tunnel of 1 in 97. During the thirty-three years that have elapsed from the opening of this portion of the line in 1837 up to last March, the traffic through the tunnel was conducted by means of an endless rope and a pair of winding engines fixed at the top of the incline. All trains coming up the tunnel from the Liverpool station were attached to the rope and hauled up by the winding engines; the trains in the reverse direction were controlled in their descent by the addition to them of very heavy break-trucks specially constructed. The delays occasioned by the stoppage of every up train at each mouth of the tunnel, for the purpose of attaching and detaching the rope, though not of great consequence in the early days of the railway, had been of late years attended with inconvenience, particularly during the excursion season, when the trains leaving Liverpool were often so heavily loaded that they were necessarily divided into two portions, each portion being hauled up the tunnel separately, and the train re-united at the top of the incline. These delays, together with the increasing requirements of the ordinary traffic, at length induced the directors to determine to remove the rope and winding engines, and to work the tunnel by locomotives in the ordinary manner; but the employment of coal-burning locomotives in a close tunnel nearly $1\frac{1}{4}$ mile long, intimately connected at each end with passenger stations of great importance, was of course impracticable without a thorough and constant artificial ventilation.

It was at one time proposed to cut the tunnel open at various portions of its length, and convert it into a series of open cuttings connected by short tunnels, leaving the ventilation of the latter to the natural curreuts produced by the heat of the passing engines; but the cost of such a work, requiring the purchase of some very valuable building land in the centre of Liverpool, and the construction of cuttings reaching to a depth of 80 feet from the surface, appeared likely to be so great, while the action of natural ventilation in cuttings of the proposed depth seemed so uncertain, that the idea was abandoned: the more readily as it was thought not unlikely that whatever discharge of foul air might take place at the top of the cuttings would be considered a nuisance by the local authorities. The difficulties of the subject were not lessened by the fact that the lower end of the tunnel opens into a walled and roofed terminal station, and is therefore partially closed at that end, forming nearly a cul de sac.

It was suggested by the writer that the foul air might be exhausted by power at some point near the centre of the tunnel, and there discharged into the atmosphere at such a height as to avoid all possibility of a nuisance. This proposal was finally adopted, and as now in operation forms the subject of the present paper; the mode of carrying it out is shown in the general section and plan, Figs. 1 and 2, Plates 1 and 2.

The operations were begun by sinking a shaft from the surface of the ground at a point a few yards south of the tunnel A A, Plates 1 and 2, and nearly in the middle of its length. From the bottom of this shaft a cross drift B, 43 ft. 6 ins. long, was carried into the tunnel, joining it at a point 1212 yards from the lower end, and 813 yards from the upper end, and having at the point of junction a sectional area of 325 square feet. In the shaft, at a height of 37 ft. 6 ins. above the rail level, is placed a large fan F, partially enclosed in a brickwork casing, and driven by a pair of horizontal engines. The fan and engines are enclosed within a chimney, 54 feet diameter at the base and 23 feet diameter at the top, rising to a height of 198 feet above the level of the rails.

The taper mouth of the brickwork casing of the fan, as shown at C in the enlarged section, Fig. 5, Plate 5, has been chosen partly with a view to provide a free passage for the foul air in the tunnel through the casing and away up the chimney when the fan is at rest, so that a slow ventilation may be continually going on from natural causes without the assistance of the fan. In order still more to favour this natural ventilation, the flue D from the boilers and the exhaust pipe of the engine are carried into a small iron funnel E, 4 feet internal diameter, which is enclosed within the large chimney, the top of the funnel being 118 feet above the level of the rails. The whole waste heat of the fires is thus usefully employed in promoting an upward current in the chimney when the fan is standing still, and also in assisting the ventilation produced by the fan when running. These expectations of a natural ventilation have not been disappointed, as observations taken during the night, after the passage of the night mails, show that the tunnel clears itself in about 45 minutes without any action of the fan.

The Fan, which is shown in Plates 3, 4, and 5, is formed of twelve straight vanes set radially round a horizontal axle, to which they are attached by angle irons; and the whole is steadied by three sets of tie rods. The axle is made of Bessemer steel, and is carried on two bearings, 8 inches diameter and 12 inches long, fitted with brasses, the distance between the centres of the bearings being 11 ft. 9 ins. The central boss G is made of two castings of the conical form shown in Figs. 3 and 4, fitting closely upon the axle at each end and secured to it by feathers; the boss is drawn tight up against a shoulder on one end of the axle by means of a nut I at the other. A cast-iron disc J, having an external diameter of 8 feet and a thickness of $1\frac{1}{2}$ inch, is interposed between the two conical castings of the boss, and the three are securely bolted together. The vanes are formed of $\frac{1}{4}$ inch Bessemer steel plate, 7 ft. 6 ins. wide and 7 ft. 2 ins. long; they are straight from heel to tip, and are set radially to the axle. Each of them is attached to the central disc J by means of a pair of 5 inch angle irons rivetted to the vane and bolted one on each side of the disc. The angle irons

reach within 12 inches of the tips of the vanes, and are strengthened laterally by $\frac{3}{4}$ inch round tie rods H, one of which is attached to each angle iron at the point shown, and reaches thence to the end of the central boss G, where it is secured to a wrought-iron ring shrunk on the casting. The tips and heels of the vanes are held in position by two double sets of flat tie rods K, Fig. 5, which are $2\frac{1}{2}$ inches by $\frac{1}{2}$ inch section, and are provided with a right-and-left-handed screw-coupling L, so that they can be drawn up to any required degree of tightness.

The external diameter of the fan is 29 ft. 4 ins., its width is 7 ft. 6 ins., and the central openings are 15 ft. diameter. The area of the central openings is thus twice that of a circle 15 feet diameter, or 353 square feet; and the circumferential opening at the heels of the blades is in length the circumference of a circle 15 feet diameter, and in width 7 ft. 6 ins., giving an area of 353 square feet, or the same as that of the central openings. These are the proportions recommended by Mr. Buckle in his paper on the Fan Blast read before this Institution in 1847. The central area is almost entirely available as an air passage, the obstruction caused by the light angle irons and tie rods being very trifling.

The brickwork casing is formed for the first half of the circumference to a circle of 30 feet diameter and concentric with the fan; the remaining portion is struck with a radius of 28 feet, thus forming a wide expanding mouth, as shown in Fig. 5. The width between the sides of the casing is 7 ft. 8 ins., Figs. 3 and 4. The clearance between the fan and the casing is consequently 4 inches at the circumference and 1 inch at each side. To the top girder is attached a deflector plate M, Fig. 5, set at an angle which was adopted after trial of various angles as giving the most favourable direction to the escaping current for discharge by the chimney, and producing also the least noise and vibration.

The engines N, Plates 3 and 4, are of the ordinary horizontal type, with cylinders 26 inches diameter and 24 inches stroke. The crank shaft is in the same line with the fan shaft, to which it is coupled directly by two flange couplings and an intermediate shaft P. The boilers, shown in the plan, Fig. 2, are three in number

and of the ordinary single-flued pattern, 5 ft. 9 ins. diameter and 30 feet long; two only are kept in steam together, the third being a spare one. The exhaust steam from the engine passes on its way to the funnel E, Fig. 1, through a Petrie's extractor, in which a portion is condensed and mixed with the feed water of the boilers.

It is found in practice that when the fan is running at about 45 revolutions per minute, the tunnel is cleared of steam and smoke in about 8 minutes after the entrance of a train at the lower end. As however the train passes through the whole tunnel and arrives at the upper end in about 3 minutes after its entrance, it follows that the first puff of steam discharged by the engine as it enters the tunnel at the lower end is drawn to the cross drift in 8 minutes; and that the last puff made as the engine emerges at the upper end is drawn to the cross drift in about 5 minutes. The upper end is however found under ordinary conditions of weather to be cleared an appreciable time before the lower end; and hence about $4\frac{1}{2}$ minutes may be taken as the average time occupied in drawing the steam and smoke from the upper end to the cross drift. The length from the lower end to the cross drift is thus completely emptied in 8 minutes of the air it originally contained; while the length from the upper end to the cross drift is emptied once in the last $4\frac{1}{2}$ minutes, and therefore in the 8 minutes the upper length is emptied of its contents $8 \div 4\frac{1}{2} = 1{\cdot}8$ times.

The lower length of the tunnel contains 1,563,000 cubic feet or $52\frac{1}{2}$ tons of air, the upper length 1,049,000 cubic feet or 35 tons of air; and the total weight of air moved is therefore $52\frac{1}{2}$ tons from the lower length, and $1{\cdot}8 \times 35$ or 63 tons from the upper length, making a total of $115\frac{1}{2}$ tons of air drawn through the fan and discharged at the top of the chimney in the 8 minutes, which is equal to $14\frac{1}{2}$ tons or 431,000 cubic feet per minute. Observations made on the pressure of the air at four different positions, when the fan was in motion at a speed of 45 revolutions per minute, have given the following mean results:—

Vacuum in tunnel, 10 yards from cross drift .	0·14 inch of water.
Vacuum at exit from cross drift	0·27 ,,
Vacuum at entering orifice of fan . . .	0·54 ,,
Plenum at discharge orifice of fan . . .	0·19 ,,

From these figures it is evident that a very large portion of the total resistance to motion is experienced by the air after it has left the tunnel proper and entered the cross drift. Taking the vacuum as being $\frac{1}{2}$ inch of water at the entering orifice of the fan, the horse power actually exerted in drawing the air up to the fan is 34 horse power; and taking the plenum at the discharge orifice as being 2-10ths inch of water, the horse power actually exerted in projecting the contents of the tunnel up the chimney is $13\frac{1}{2}$ horse power. Hence the total power actually exerted upon the air is $47\frac{1}{2}$ horse power.

The diagrams shown in Fig. 6, Plate 6, represent the case of a train passing up the tunnel from the lower to the upper end in three minutes, leaving behind it a trail of steam and smoke to be cleared out by the fan situated at B. The different views represent the condition of the tunnel at the end of each successive minute from the first entrance of the engine at 0, to the exit of the engine at 3 minutes, and until the last portion of steam and smoke is exhausted from the tunnel at 8: on the assumption that the steam and smoke travel at a uniform velocity, which cannot be far from the truth.

It will be noticed that the fan is not placed precisely in the centre of the length of the tunnel, but rather nearer to the upper end, being situated 813 yards from the upper end and 1212 yards from the lower. The reason for this is that the trains passing down from the upper to the lower end do not foul the tunnel at all, as they descend the incline by gravity without the action of the engine. The fan is therefore run only during the passage of an up train; and as the lower length begins to be exhausted as soon as the engine enters the tunnel, whereas the upper length is usefully acted upon only after the exit of the engine, it was necessary to reduce proportionately the length of the upper portion. Experience shows that this has been a little overdone, the upper length being, as before stated, almost always clear before the lower; but the exact position of the fan was decided by the convenience of buying land on the surface at this spot. It is in contemplation to raise the rail level at the upper end of the tunnel, and thus make the line, which now drops from

the upper station towards the tunnel, level throughout the station yard. Such an arrangement will have the effect of retarding the air in the upper length, and proportionately increasing its velocity in the lower, thus probably restoring the balance.

As the trains do not follow each other throughout the whole day at such short intervals as eight minutes, the fan is not kept constantly running, but is started and stopped as required by the following arrangement. An electric bell fixed in the engine house is worked by the signalman at the lower end. As each train starts from the platform, the policeman sets this bell ringing; the engineman obeys the signal by starting the engine, and keeps it in motion until the discharge from the fan becomes quite clear, showing that no steam or smoke remains in the tunnel. The engine is then stopped, and remains standing until the signal is received that another train has left the platform. A similar bell in the boiler house, attached to the same wire, informs the fireman of what is doing, and enables him to adjust the fires as required.

From the foregoing description of the action of this system of ventilation it will be seen that the ends of the tunnel are always clear, the action of the fan being to collect all the foul air towards the centre for its discharge; and as a good deal of shunting is done inside the lower end of the tunnel, this is a great practical advantage. The fan having only been in full work since March last, it is not possible as yet to state definitely what will be the annual cost; the wear and tear however must necessarily be very trifling.

Mr. E. A. Cowper thought that the ventilating fan described in the paper answered its purpose very well; and the time taken in clearing the tunnel being only eight minutes from the entrance of a train, the rate of ventilation was amply rapid enough. He thought however that the fan would work better if the case were made spiral

round the whole circumference, instead of for only half way round, as he believed the spiral was the best shape for the casing of a fan. From calculations that he had made for ventilating by means of exhausting pumps a railway tunnel 22 miles long, he had found that it was practicable to do so even for that extreme length; but the power required to accomplish the object was very great, and the difficulties attending the operation would be much increased by the circumstance of the trains having in that case to run through in both directions with steam on, which would require a much greater ventilating power than where trains simply followed one another in the same direction, as in the case described in the paper. He enquired what was the indicated horse power of the fan engine described in the paper.

The PRESIDENT replied that the power of the engine was considerably in excess of the duty done as represented by the air discharged from the fan; and at the ordinary working speed of 45 revolutions per minute he believed the indicated power of the engine was about 150 horse power.

Mr. W. COCHRANE thought it would be very desirable to make some experiments for ascertaining the duty actually done by the fan in ventilating the tunnel. With the size of engine employed for driving the fan, working at 45 revolutions per minute and discharging 431,000 cubic feet per minute as given in the paper, the low water-gauge of only about ½ inch at the entering orifice of the fan case would not represent a useful effect of more than 23 per cent. of the power exerted, if that amounted to 150 horse power. In the ventilation of a mine however, which was a case very similar to that of the railway tunnel described in the paper, the Guibal ventilating fans now employed in this country of 30 feet diameter exhausted as much as 150,000 cubic feet of air per minute with a vacuum of 3 inches of water gauge, and gave a useful effect of about 60 per cent. of the power applied; one of these ventilators had been constructed as large as 45 feet diameter, and would shortly be at work. With this form of mine ventilator, which he had found the most effective, and of which descriptions had been given at previous meetings of the Institution (see Proceedings Inst. M. E.

1869 pages 78 and 140), the consumption of coal for driving the ventilator could now be relied upon not to exceed 3 lbs. per indicated horse power per hour; or rather less than 5 lbs. of coal per hour, per horse power of the air drawn from the mine. With the tunnel ventilator that had been described he thought the duty would be found to be much inferior; and considering the low water-gauge, there should be no difficulty in getting a better result than appeared to be obtained. With regard to the shape of the fan case, he felt satisfied that the spiral form was not correct, and that the concentric case of the tunnel fan was the right form. If the chimney into which the fan discharged could have been built inverted, with the area expanding upwards in suitable proportion as in the Guibal fan, it would have had the advantage of increasing the useful effect of the fan to the extent he believed of fully one third, by utilising a portion of the velocity in the discharged air.

The PRESIDENT said he was aware there was a difference of opinion on the subject of the shape of the fan case, and he was inclined to the spiral case, which was the form that had been originally intended to be adopted; but owing to an unintentional deviation in the construction of the casing, it had been built concentric for the first half of the circumference. The fan however had not been designed simply with a view to the best theoretical form; but an important object which it had been necessary to keep in view had been to effect as good a ventilation as possible while the fan was at rest, seeing that during the whole of the night service and a portion of the day the fan was not required to be worked, and it was only running about eight hours out of every twenty-four. He had no doubt it was the fact that fans on the Guibal principle gave a much higher result in duty; but with the object of employing natural ventilation for the tunnel during the greater portion of the time, some departure had seemed advisable in this instance from what was now generally considered the best form of ventilating fan; and perhaps the best commercial result had been obtained in this way. The chimney over the fan had been built taper, and largest at the bottom, in order that all the heat of the engine-house with the rest of the waste heat might be got inside the chimney at the

bottom, so as to aid as far as possible the natural ventilation produced by the chimney. No doubt an inverted chimney in the form of an expanding funnel would have been preferable, had it been practicable, as it would have given a lower velocity to the discharged air, and less work would therefore have been lost in the air.

Mr. G. Fowler asked how the low percentage of useful effect estimated to be realised by the fan was accounted for.

The President said there was a considerable difference of opinion and of practice in the mode of applying the water gauge to ascertain what the vacuum really was, and there were corresponding discrepancies in the degree of vacuum noted: it was not satisfactorily decided whether the leg of the gauge should be set in the direction of the current, or opposed to that direction, or at right angles to it. There was certainly a great difference in the results, according to the mode of applying the gauge, and he had not found any mode of using it which he considered altogether satisfactory; the data for the calculation of the duty performed were consequently uncertain. The figures given in the paper for the amount of vacuum had been checked by the readings of an aneroid barometer as far as practicable.

Mr. W. M. Moorsom observed that the results which had been arrived at by Mr. Berthon in the important experiments made by him upon the measurement of a current of water, in connection with his plan of ship's log, would perhaps throw some light upon the question of the proper position of a water gauge for measuring air currents. With that instrument, in which a vertical tube with closed bottom and having a circular orifice made in its side was immersed in the water below the ship's keel, and connected at its upper end to one leg of a mercurial gauge, it had been found that when the orifice was turned exactly forwards, in the direction of the ship's motion, the mercury rose in the gauge to the correct height corresponding with the particular speed under trial. When the speed was such that a column of mercury was supported of 4 inches above zero, with the orifice pointed exactly forwards, then if the orifice was turned half round to point exactly astern, the mercury fell to 2 inches below zero; and if turned exactly at right angles to

the direction of motion, the mercury fell to 6 inches below zero at the same speed; but a perfectly neutral position was found to be when the orifice was turned partly forwards so as to make an angle of $41\frac{1}{2}°$ with the direction of motion, the mercury then standing at the zero of the gauge at all speeds. He thought that the same law might be expected to hold good with regard to the measurement of the pressure of a current of air; and in the experiments made with the water gauge for measuring the vacuum produced by the tunnel fan, it would accordingly be inferred that, if the leg of the gauge had been turned directly from the current, the degree of pressure shown by a sufficiently delicate gauge would have been somewhat less than the real pressure in the tunnel; and that this would have been still more the case, had the leg of the gauge been placed at right angles to the current. The position adopted for the gauge in the tunnel experiments had been with the orifice directly facing the current, in which position he thought the gauge had shown a pressure not less than that corresponding with the actual tension of the current.

Mr. W. Cochrane said he had made experiments upon the question of turning the leg of a water gauge towards or from the current, in measuring the air current in a mine drift; and by turning the leg round successively throughout an entire circle, he had found that the extreme variation in the vacuum indicated by the gauge did not exceed 1-10th inch of water above and below the average, which was 2 inches in that instance. The highest vacuum was when the leg was turned at right angles to the direction of the current. The orifice of the leg of the gauge was afterwards fitted with an expanding funnel, extending to several times the diameter of the leg itself, and a similar result was obtained. Judging from the dimensions of the tunnel fan and its speed of running, he was inclined to think there must have been some mistake in the amount of vacuum observed with the water gauge, and that the correct vacuum must have been considerably greater than $\frac{1}{2}$ inch as given in the paper.

Mr. W. M. Moorsom observed that the experiments with the Berthon log had been made with water, for measuring the

velocity of a ship's motion; and the only attempt that he had been able to make, for ascertaining whether the same results held good with regard to air, had been with the tuyere of a blowing fan supplying blast at a pressure of from 4 to 8 inches of water; in this case he had found that the minimum pressure was indicated when the orifice of the gauge was directed at an angle of from 70° to 90° with the current of blast. The velocity of the current produced by the tunnel fan, when calculated from the total quantity of air exhausted by the fan during the eight minutes of its working, amounted to 20 feet per second at the two central entrance openings of the fan case.

Mr. W. Cochrane considered that the velocity of 45 revolutions per minute with a 30 feet fan would be equivalent to about 1·12 inch water gauge, instead of only $\frac{1}{2}$ inch, which had been stated as the vacuum observed at the entrance openings of the fan case. He hoped that some further experiments would be made for ascertaining the actual power expended in driving the fan, and the real amount of vacuum produced, as well as the volume of air drawn through the fan, in which he thought there must have been some error; this information was very desirable and would be of much value.

Mr. E. A. Cowper enquired whether any experiments had been made to ascertain if the air was drawn in equally in both halves of the central entrances on each side of the fan; he should expect that much less air would be drawn in at the concentric half of the casing than at the expanding half, on account of the inability of the fan to discharge the air from the tips of vanes through the concentric half of the circumference, where the vanes were running in such close contact with the casing.

The President replied that no experiments had been made to determine that point, and he was not sure that it would be practicable to get at any result with sufficient exactness to be of value. It was certainly clear that if the fan blades were in immediate contact with the concentric half of the casing—as close as they could possibly be without actually touching the casing,—there could be no discharge of air from the fan throughout that half of the circumference; and this consideration was so far in favour of a spiral casing. The fan

had indeed been made just 30 feet diameter in the first instance, so as to run as close to the casing as was possible; but an objectionable vibration and noise was then produced in the working of the fan, and the size of the vanes had therefore been reduced so as to leave a clearance of 4 inches between the tips of the vanes and the casing, and 1 inch clearance at each side of the fan. This clearance had the effect of entirely removing the vibration and noise, and it was now impossible in the street close by to tell whether the fan was at work or not.

Mr. J. B. Fenby enquired whether there was any difference in the time required to clear the tunnel by the fan, according as the weather was foggy or clear.

The President replied that foggy weather was found to increase the time required for clearing the tunnel.

Mr. F. J. Bramwell said that, with regard to the question which had been raised as to the mode of measuring currents of air by a water gauge, he had made the experiment of allowing a jet of water to issue horizontally from a cistern under a constant head of 4 feet, and directing the jet against the horizontal nozzle of a vertical glass tube which was carried up to the height of the water level in the cistern; and he had then found that the issuing jet upheld a column of water in the vertical tube to the height of 3 ft. $11\frac{3}{4}$ ins., or practically to the level of the water in the cistern. From this experiment therefore he was led to the conclusion that if a bent tube were inserted into any running stream, with the orifice of the tube turned to face the stream, the water would rise in the tube to the exact height corresponding to the velocity of the stream; and in measuring a current of air by a water gauge he inferred that the correct result would be obtained by turning the leg of the gauge to face the current. He hoped the further experiments upon the vacuum produced and the work actually done by the fan would be extended so as to determine the skin resistance of the tunnel, which he considered must be very great in a tunnel of that length; and he proposed a vote of thanks to the President for his paper, which was passed.

The following paper was then read:—

DESCRIPTION OF A BALANCED SLIDE-VALVE FOR LOCOMOTIVE ENGINES.

By Mr. WILLIAM G. BEATTIE, of London.

The ordinary Slide-Valve that is generally used in locomotives has the serious disadvantage that the pressure upon it when working is so heavy as to cause great wear of the rubbing faces of the valve and cylinder ports; and the force expended in overcoming the friction is a considerable loss of power, and involves serious wear of the valve gear, and difficulty in quickly altering or reversing the action of the valve.

An ordinary locomotive slide-valve is shown in Figs. 7 and 8, Plate 11, having 1 inch outside lap; and the area of this valve that is under pressure during the portion of the stroke in which steam admission takes place, which may be taken at one third of the stroke, extends from the edge of the steam port at A to the end of the cylinder-port facing at E, being 10 ins. length by 17 ins. width of the valve over the flanges, or an area of 170 sq. ins. under steam pressure, for an engine with 17 ins. cylinders. During the remaining two thirds of the stroke after the steam port is closed, the whole area of the valve is under steam pressure, being $10\frac{1}{2}$ ins. length by 17 ins. width, or 178 sq. ins. area; and this gives an average throughout the stroke of 176 sq. ins. area, which at 125 lbs. per inch pressure of steam in the valve chest amounts to a total pressure upon the back of the valve of 22,000 lbs.

From this pressure on the back of the valve has to be deducted the pressure under the valve, exerted by the steam in the cylinder; and taking the exhaust to open at two-thirds of the stroke, this pressure under the valve will be in the first third of the stroke that of the exhaust steam only, acting on the area C D of the inside of the valve, Fig. 8. In the second third of the stroke, Fig. 9, there

will be in addition the pressure of the expanding steam within the cylinder acting upon the area of the steam port A B; and in the last third of the stroke, Fig. 10, there will be the pressure of the exhausting steam from the cylinder acting on the inside of the valve with the addition of an average area of half the steam port, and also the pressure of the compression at the other end of the cylinder acting on the area of the other steam port. From the results of indicator diagrams taken with the same pressure of steam, 125 lbs. per inch, at a speed of 20 miles per hour, these several pressures may be taken as follows, as shown in the approximate indicator diagram, Fig. 11. In the first and second thirds of the stroke, 5 lbs. per inch for the exhaust steam pressure; in the second third 81 lbs. mean pressure of the steam in the cylinder expanding from 125 lbs. into double the volume; and in the last third of the stroke 16 lbs. mean pressure of the exhausting steam, and 33 lbs. mean pressure of the compression. The size of the steam port being $14\frac{1}{2}$ by $1\frac{1}{4}$ ins., and the inside of the valve $14\frac{1}{2}$ by 6 ins., or 18 and 87 sq. ins. area respectively, the total pressure under the valve amounts to 435 lbs. in the first third of the stroke, 1901 lbs. in the second third, and 2133 lbs. in the last third, or a mean pressure of 1490 lbs. throughout; and deducting this from the 22,000 lbs. pressure on the back of the valve, there remains an effective pressure of 20,510 lbs. or 9 tons upon the back of each valve, and 18 tons upon the pair of valves. In the valves of the passenger engines on the South Western Railway the outside lap is $1\frac{1}{2}$ inch, instead of 1 inch as in the above calculation, which increases the pressure upon each valve to 10 tons.

For the purpose of measuring the actual power required to move the valves under these circumstances, experiments have been tried by the writer by removing the valve link-motion of an engine, and connecting the valve-spindle to a lever having the proportion of 20 to 1; from the extremity of the lever a cord was led over pulleys to the front of the engine, and weights were there hung on the cord until the valve began to move, a steam pressure of 125 lbs. per inch being maintained in the valve chest. In the first experiment, which was several times repeated, the weight required to move the valve

was 308 lbs., amounting to a force of 6160 lbs. exerted on the valve spindle. But as the motion of the valve when once started became rapidly accelerated, a smaller weight was applied to the cord, and the valve was started by hand; and the weight then required to maintain motion steadily in the valve was found from several experiments to be 231 lbs., amounting to a force of 4620 lbs. at the valve spindle. Then taking the length of stroke of the valve to be 4 ins. and the stroke of the piston 22 ins., the power required to be exerted at the piston to maintain the motion of the valve will be $\frac{4}{22} \times 4620$ lbs., or 840 lbs. To this has to be added the power required to overcome the friction of the eccentric straps; and as this acts on a diameter of 14 ins., the proportionate force at the piston will be $\frac{14}{22} \times 4620$ lbs., or 2940 lbs.; and taking the coefficient of friction at one twelfth, the power required at the piston will be $\frac{1}{12} \times 2940$ lbs., or 245 lbs. The total of the two resistances amounts to a force of 1085 lbs. at the piston, and the piston being 17 ins. diameter, this is a constant deduction of 5 lbs. per square inch from the effective steam pressure upon the piston, or a loss of about 8 per cent. of the effective power of the engine.

For the purpose of reducing this serious loss the Balanced Slide-Valve forming the subject of the present paper has been designed by the writer. In Figs. 1 and 2, Plates 7 and 8, it is shown as applied to outside-cylinder passenger engines, and in Fig. 6, Plate 10, as applied to inside-cylinder goods engines.

The body of the valve F is similar in shape to the old D valve, being made cylindrical at the back, Figs. 2 and 6; and it works inside a jacket G of corresponding form, fixed in the steam-chest by the studs H H, Fig. 2. The steam pressure is excluded from the back of the valve by two steam-tight packing rings J J, Figs. 1 and 3, one at each end of the valve, which are fitted into grooves in the body of the valve, and are pressed outwards against the jacket by the spiral springs L L placed radially. At the lower side of the valve, the back is turned to the same radius as the jacket for a short portion K of the arc, Figs. 2 and 6, and is there in contact with the jacket; the remaining portion of the back is shaped to a smaller radius, so as to

be 1-16th inch clear of the jacket. The packing rings J are pressed by the studs I into the upper angle formed by the jacket and cylinder face, opposite to the lower angle filled by the body of the valve at K. Steam is admitted behind the rings by suitable openings, and the rings are grooved, as shown in section at J J in Fig. 1, to reduce their surface in contact with the jacket. In Figs. 4 and 5, Plate 9, are shown two other arrangements of the packing rings that have been tried.

The position of the packing rings at each end of the valve is determined by the width of the steam port, as it is necessary to expose to steam pressure at each end of the valve an extent of the back of the valve equal to the area of the port, in order that the valve may not be lifted from the cylinder face by the pressure of steam in the cylinder after the cut-off has taken place. As the space intervening between the two packing rings in Fig. 1 is the portion that is free from pressure, the necessary area for the steam pressure on the back of the valve is obtained by setting back the inner edge of each packing ring to the required distance from the end of the valve. The spindle of the valve is a straight bar passing freely through it and held in position by the cotter N. The back of the valve may be open, as shown in Figs. 1 and 3; or it may be closed in, and the exhaust passage bridged over so that the steam may pass through the valve from one end of the steam-chest to the other. The valves are made by preference of hard cast-iron, and the packing rings are also of cast-iron.

For the purpose of measuring the actual power required to move these balanced valves, an experiment was carried out similar to that before described for the ordinary valves. The result obtained was that a weight of 98 lbs., equal to a force of 1960 lbs. acting at the valve spindle, was required to move the valve from rest; and a weight of 70 lbs., equal to a force of 1400 lbs. acting at the valve spindle, was required to maintain motion. It appears therefore that whilst a force of 4620 lbs. was required to move the ordinary brass valve, the balanced cast-iron valve was moved with a force of 1400 lbs., or only 30 per cent. of the power required to move the ordinary valve. The amount of pressure on the back of the

balanced cast-iron valve is equal to the pressure of steam at 125 lbs. per square inch, acting on the area of $1\frac{1}{4} \times 17$ inches at each end; and the area of the ungrooved packing rings (Figs. 4 and 2) in contact with the jacket is 1×22 inches for each ring; the total area of rubbing surface under the pressure of 125 lbs. per inch is therefore 86 square inches, giving a total pressure of 10,750 lbs. Taking then the coefficient of friction to be one tenth, the power required to move the valve should be 1075 lbs., and by actual trial it amounted to 1400 lbs.

In reference to the results practically obtained by the employment of these balanced valves, the first point to be noticed is the mechanical advantages attending their use; and not least important is the facility of moving the reversing lever with steam on, and the avoidance of the excessive wear and tear to which the ordinary valves and the link-motion working them are subjected. It has been found also in practice that there is a considerable saving both in first cost and maintenance with the balanced valves. As the strain upon the valves is so much reduced, they may safely and advantageously be made of light construction, and of cast-iron in place of brass; and thus the first cost is much diminished. The cost of a pair of ordinary brass valves and spindles complete for main-line coupled passenger engines averages £13 13*s.*; while the cost of a pair of balanced valves complete for the same class of engine is only £5 7*s.* There is thus a saving of £8 6*s.* per engine in first cost. The cost of a pair of ordinary brass valves and spindles complete for passenger tank engines amounts to £10 2*s.*, while the cost of the balanced slide-valves and spindles for the same class of engine is only £4 18*s.*, showing a saving of £5 4*s.* in first cost. The cost of a pair of ordinary valves and spindles complete for six-wheel-coupled goods engines is £11 11*s.*, while the cost of the balanced valves is £6 19*s.*, showing a saving of £4 12*s.* per engine in first cost.

With regard to maintenance, it has been found that the wear of the balanced valves is very slight, and it appears probable that they will last six or seven years before requiring to be renewed. Taking

therefore the life of the ordinary brass valves at eighteen months, it is evident that a great reduction in expense of maintenance is gained with the balanced valves. The packing rings require to be renewed about once a year. and the grooves cleaned out, the jackets re-bored, and the valves and cylinders faced; the expense of this repair is about £2 per engine. The valve motion requires slight repair, such as new pins, about once in two years; and contrasting this with the heavy repairs required by the ordinary valves and valve motion, it is seen that there is a great economy in favour of the balanced valves.

Another source of economy is the saving in power required to work the balanced valves, and the consequent saving in fuel, which is an important consideration on railways, where fuel is so expensive. By reference to the recorded consumption of fuel per mile on the London and South Western Railway by twelve engines after being fitted with the balanced valves, as compared with their rate of fuel consumption previously when working with the ordinary valves, and taking a period of twelve months in each case for comparison, it has been found that the passenger engines have consumed $2\frac{1}{2}$ lbs. less coal per mile since they were altered. It is expected that after some extended experience an average saving of at least $2\frac{1}{2}$ lbs. per mile with both passenger and goods engines will be the result; and this amount becomes important when taken as extending over the whole mileage of the year.

Finally it may be stated that no greater difficulty is found in keeping the balanced valves steam-tight than is experienced with the ordinary pistons; and that no instances of valves or valve spindles breaking have occurred up to the present time. As many as 180 engines have been fitted with the balanced valves, which are now applied to all engines either newly built or in shop for repair, the results of the past $2\frac{1}{2}$ years' working having proved so satisfactory.

Mr. W. G. Beattie said that in making the experiments upon the power required to move the ordinary brass slide-valves under steam pressure, he had had one of the valves in a locomotive taken out and carefully faced up, and the port faces also scraped up perfectly true; and had then put the valve to work for four or five days before making the experiment upon it, taking care to keep it well lubricated all the time. The valve was consequently in excellent condition when the trial was made of moving it under the steam pressure by a dead weight; and the force of 4620 lbs. on the valve-spindle, which was required to move the valve when just started into motion, represented therefore the constant force necessary to work an ordinary brass slide-valve when in the very best condition. The other slide-valve in the same engine, which had not undergone facing up and was in the ordinary worn condition of a slide-valve after a moderate time of work, required a considerably greater force to work it. The cast-iron balanced valve however, which was moved by a force of only 1400 lbs. on the valve-spindle, was tried in its ordinary working state, and showed therefore the great advantage resulting from the removal of the heavy pressure of steam on the back of the valve. An important point in favour of the balanced valves was the length of time they continued in good working order without requiring any attention beyond regular lubrication; if they were not well lubricated they became slightly grooved on the face, more so indeed than the ordinary brass valves, as they were made of cast iron and worked on the cast-iron port-face of the cylinders; but when properly lubricated, they were found to continue in good working order for eighteen months, without requiring any examination. After working for that period, the packing rings on the back of the valve, which when new were a good fit, had acquired a certain amount of play and wanted renewing; it was found necessary also to clean out the grooves, re-bore the jackets, and re-face the cylinder faces and the valves themselves, all of which was done by machinery at the cost of about £2 per engine. Care had to be taken that the packing rings were put in neither too tight nor too slack, so as to avoid any unnecessary amount of pressure upon the valve from the packing, and on the

other hand to prevent any risk of steam getting past the rings and escaping into the exhaust port.

The first construction of packing that he had tried had been the one shown in Fig. 4, where the rings were simply piston-rings fitted into plain grooves turned in the back of the valve, and were pressed outwards against the jacket by the radial springs. In this case however the packing was only steam-tight so long as the rings continued a good fit in the grooves, and when they became loose laterally in the grooves from the effects of working, the steam penetrated behind the rings and exerted pressure on them, causing additional wear. He had tried next the plan of admitting the steam behind the packing rings, as shown in Fig. 1, so as to render the valve steam-packed by the pressure of the steam aiding the springs in keeping the rings steam-tight against the jacket; but the rings were then found to wear away much more quickly, on account of the increased pressure upon them. In the plan of packing shown in Fig. 5 however, which he had lately tried with very good results, lateral springs were added upon the inner faces of the packing rings, for the purpose of resisting the pressure of the steam upon the exposed annular area of the outer face of the rings, so as to keep the rings as nearly as possible in equilibrium laterally whilst working, and to preserve a steam-tight joint between the outer face of each ring and the contiguous side of the groove in which it lay. These lateral springs were made to exert an outward pressure of 150 lbs. each, two of them being provided to each ring; the radial springs, pressing the packing rings outwards against the jacket, exerted a total pressure of 150 lbs. upon each ring, which was equivalent to only about $6\frac{1}{2}$ lbs. of steam pressure per square inch over the area of the rubbing surface of the rings. This amount of radial pressure was sufficient to overcome the friction of the rings inside the grooves, and keep the rings always in contact with the jacket; there was thus a constant slight pressure of the rings against the jacket, whether the steam were on or not, and it was much better to have only this constant small pressure than to have also in working the additional heavy pressure of the steam-packed rings shown in Fig. 1.

The application of the balanced valves to goods engines with inside cylinders was not so easy as to outside-cylinder engines; and the wear of the valves was considerably greater, because the angle between the jacket and cylinder-face, in which the weight of the valve rested, was more acute in the inside-cylinder engine, Fig. 6, than in the outside-cylinder, Fig. 2. In each case the wear began at the bottom of the valve, the weight of which caused it gradually to work itself further down into the corner between the jacket and cylinder-face, and it thus kept itself steam-tight at the bottom; round the upper portion of the back of the valve it was kept steam-tight by the packing rings being pressed outwards against the jacket, and each ring was kept well pressed up into the top corner of the jacket by the upper stud, which was made to bear in a notch on the under side of the ring, as shown in Figs. 2 and 6. By this means the valves were found to be maintained quite steam-tight, without any sound of steam blowing through past the packing, so long as they were properly lubricated; the only circumstances under which they would not be steam-tight were if they were neglected and left to work dry, in which case the steam would blow through on the face of the valve as well as past the packing rings at the back; but with ordinary care the valves could be kept perfectly steam-tight, without any leakage at all.

The President enquired whether the balanced valves had been in use a sufficiently long time to show any definite result as to the wear of the valve motion.

Mr. W. G. Beattie replied that in the "Saracen" engine, in which the balanced valves had now been in constant work for two years and a half, the valve motion had not required repairing during that time, and continued still in good working order. It had only been found necessary to replace two or three of the centre pins, which required to be renewed about every year or two years; but the rest of the valve motion had not yet worn enough to afford any data for deciding the actual difference in the repairs required. The surfaces of the slotted links were not worn at all at present.

Mr. F. J. Bramwell said he had been on an engine fitted with these balanced valves in the experiments which he had made a year

ago on the counter-pressure steam break (see Proceedings Inst. M. E. January 1870 page 41), and he had found there was not the slightest difficulty in reversing the engine by the hand lever under the full pressure of 120 lbs. steam whilst running. The ease of reversing these valves under steam presented a marked difference from the ordinary valves, and there could be no doubt this was a great advantage for counter-pressure working, enabling the engine to be reversed easily by hand with the ordinary reversing lever, while the steam was on, without the necessity for screw reversing gear for the purpose. On calculating the horse power expended in working the ordinary valves, it was found to reach a very large amount; for taking the figure given in the paper, 4620 lbs., as the force required to move the ordinary valves, the horse power required to overcome the friction of the pair of valves with 4 inches stroke, in running at the speed of 40 miles an hour with driving wheels 6 ft. 6 ins. diameter, amounted to about 33 horse power; and to this had to be added the friction of the eccentrics, which appeared from the paper to be about two sevenths of that of the valves, making altogether 42 horse power expended in working the ordinary unbalanced valves, when running at 40 miles an hour. With the balanced valves requiring only 30 per cent. of the power, there would consequently be a saving of about 29 horse power at that speed of running, which at $3\frac{1}{2}$ lbs. of coal per horse power per hour would represent a saving of $101\frac{1}{2}$ lbs. per hour—a sufficiently near approximation to the observed saving of $2\frac{1}{2}$ lbs. per mile, which at the speed of 40 miles an hour amounted to 100 lbs. per hour. This was certainly a very large saving to be effected by the use of the balanced valves, altogether irrespective of the question of any saving in the wear of the valves themselves and the valve motion; and with regard to the latter point also, there could be no doubt that they were an important step in the working of locomotives, as there was not the slightest whistle or sound of leakage when the steam was turned on at starting, until the engine gave the first fair beat of the exhaust, showing that the valves were absolutely steam-tight.

Mr. E. A. Cowper said he fully concurred in the usefulness of the balanced valves, and from what he had seen of their working he was thoroughly satisfied of their value.

Mr. J. Robinson enquired what provision there was with the balanced valves for getting rid of the water which accumulated in the cylinders when the engine was standing, sometimes to such an extent that the cylinder cocks could not carry it all off; in that case, with the ordinary valves, the water escaped under the valves into the blast-pipe by lifting them slightly off the cylinder face.

Mr. W. G. Beattie replied that in the balanced valves it was only at the bottom corner that the valve itself bore upon the jacket for a short distance round the back of the valve, as shown in Figs. 2 and 6; and round the greater part of the circumference, the back of the valve itself was turned down 1-16th or 1-8th inch clear from the jacket, that space being made steam-tight by the packing rings. This allowed the valve to be canted off the face at the upper part, to a sufficient extent for the escape of water from the cylinder, in the same manner as the ordinary valves were lifted under such circumstances.

Mr. F. J. Bramwell enquired why it was that the system of double-port valves, which was now in universal use for marine engines, was not considered practicable for locomotives. With the double-port valve the length of surface to be travelled over in each stroke was reduced to one half, as compared with the ordinary single slide-valve; and although of course the total pressure on the back of the valve was not reduced, yet the power required to work the valve was reduced very nearly to the extent of one half.

Mr. J. Robinson observed that the use of double-port valves would also halve the friction of the eccentrics, as well as that of the valves. He understood another form of balanced slide-valve, that of Mr. Adams, had been tried on the Midland Railway, and enquired what had been found to be the results of its working.

Mr. W. Kirtley said that in that valve the steam pressure was excluded from the greater portion of the back of the valve, over the circular areas included within a couple of brass rings, which were let into the flat back of the valve, and were pressed outwards by springs

against a fixed flat back-plate, faced for them to work against. They had tried this valve some time ago on the Midland Railway, but had found the difficulty was to get the rings to continue a good fit against the back-plate for any length of time; after working for a short time the rings were no longer steam-tight, so that the valve ceased to work as a balanced valve, and became then worse than an ordinary unbalanced slide-valve.

The PRESIDENT observed that he had not seen previously the balanced valve described in the paper, and thought it was certainly one of the best of that class of valve. There was one difficulty however attending the working of balanced valves, which he believed would prove a considerable objection to all of them, in addition to the difficulty of keeping them steam-tight in working; and that was the fact that when the engine was running without steam, down inclines or in approaching stopping stations, the balanced valve, unlike the ordinary one, was not raised from the working face by the pressure of the exhaust steam beneath it; a partial vacuum was consequently maintained in the steam chest, and the engine could not be expected to run so easily or freely with the steam off, as when the ordinary valves were used. This was one of the objections that he had felt to balanced valves, and it appeared to him to be one of considerable weight: he understood it had also been confirmed by the experience on the North London Railway, where the other plan of balanced valves that had been referred to had been tried for some time and had subsequently been discontinued, their wear having been found to be much greater than that of the ordinary valves. On the other hand, so long as the balanced valves could be maintained in good working order, there was no doubt their use must result in a material saving in wear and tear of the valve motion. There were many things however that were mechanically right, which were not commercially successful, and it was only extended use that could prove the practical utility of the balanced valve for locomotive engines. With regard to the double-port plan of valve that had been referred to, the total pressure upon the valve was increased in that case, and though the length of travel was reduced to one half, this reduction in the

extent of motion involved the serious objection that the lead of the valve being reduced in the same proportion at each of the two steam ports could not be adjusted with so much nicety, and at the same time the wear in the numerous joints of the valve gear would produce double the effect in disturbing the adjustment of the valve. Many arrangements of valve were practicable in stationary or marine engines that were not so desirable in locomotives, on account of their high speed of running, which rendered lightness a point of great importance in the construction of the valves.

Mr. J. Robinson remarked that, with regard to the abandonment of balanced valves on the North London Railway, the objection to them, on the ground of their having to work constantly under the pressure of the packing springs when the steam was off, would tell much more he supposed on a line like the North London, where there were many stoppages, with short distances between, and consequently a greater proportion of running with steam off, than on other railways with longer distances, as on the London and South Western line.

The President moved a vote of thanks to Mr. Beattie for his paper, which was passed.

The following paper was then read :—

ON WHITTLE'S PLAN FOR PREVENTING DEPOSIT AND INCRUSTATION IN STEAM BOILERS.

By Mr. GEORGE ADDENBROOKE, of Darlaston.

The efficient and safe working of Steam Boilers requires that the heating surfaces should be kept clean for the uninterrupted transmission of the heat to the water, and that a continuous free escape should be provided for the globules of steam formed on the surface of the heating plates; and the importance of this provision becomes increased with the increase of steam pressure now adopted for economising fuel. The presence of even a thin incrustation of scale upon a boiler plate seriously obstructs the transmission of heat to the water, the scale being, it is considered, as much as thirty times inferior to wrought-iron plate as a conductor of heat; consequently a boiler plate having a quarter of an inch of incrustation upon it, which is a thickness often existing in boilers, would practically be equivalent to a total thickness of probably eight inches of iron; and therefore, when exposed to a good flame, a plate so incrusted necessarily gets heated to a much higher temperature than that of the water in the boiler, and runs the risk of becoming dangerously weakened.

The water used for the supply of steam boilers generally contains impurities, which are precipitated by the evaporation of the water, and when first heated rise to the surface in the form of a scum; they subsequently sink to the bottom and accumulate upon the heating surface of the boiler, preventing the actual contact of the water with the heated plates. The incrustation thus formed is often attached so firmly to the plates as to require for its removal an amount of force that proves very injurious to the structure of the boiler; and in consequence of the incrustation continually increasing in thickness, from the time when the boiler is put to work until it is stopped for cleaning, so great an obstruction is caused to the

passage of the heat into the water that the evaporative power of the boiler is much diminished. In many cases the incrustation becomes so thick that the water cannot carry off the heat with sufficient rapidity from the plates to prevent their getting red-hot; and this has been in some instances the immediate cause of explosion, although there may have been an abundant supply of water in the boiler at the time of its giving way.

It is however not only the formation of incrustation upon the heating surfaces of a boiler that is a source of danger, but it is now satisfactorily proved that an important portion of the impurities in the water remain diffused through it in the form of a floury precipitate; and the water gradually becomes thickened as the quantity of this precipitate increases with the continued evaporation. Many instances of explosion are recorded, where the cause appeared at first very perplexing, as all ordinary precautions had been duly employed in working the boilers; but the explosion has subsequently been definitely traced to the excessive accumulation of this floury precipitate in the water of the boiler. It has been pointed out by the Engineer of the Manchester Steam Users' Association, Mr. L. E. Fletcher, and confirmed by the experience of others, that furnace crowns, even though they continue covered with an ample supply of water, may become overheated and dangerously bulged out of shape, if the feed water is highly impregnated with carbonate of lime, which, although it forms only a slight scale upon the plates, precipitates on evaporation a large quantity of fine flour or dust that remains floating in the water. As this material is quite loose, a good deal of it is floated away with the water when the boiler is emptied, while the remainder is readily washed out; so that the extent of the precipitate frequently escapes notice, and from the small amount of scale upon the plates the objectionable character of the water with which the boiler has been working is not suspected. When the water contains such an impurity, unless a portion of the water is blown off at frequent intervals or the boiler cleaned out often enough, it is certain that the percentage of the precipitate will rise to a dangerous point, at a rate proportionate to the quantity of water evaporated.

With regard to the action of the floury precipitate, it may on the one hand appear unnecessary to suppose it to become heaped upon the plates in order to lead to their overheating, and it may perhaps be doubted whether it settles at all so long as the boiler continues in active ebullition; but possibly by thickening the water it interferes with the escape of the globules of steam as they are generated upon the surface of the heated plates, so that they are kept longer in contact with the plates over the fire than would otherwise be the case, thereby causing the contact of the water with the plates to be interrupted and overheating to be produced. Or on the other hand, if on account of its greater density the precipitate be supposed to sink and settle upon the heating surfaces, although not possessing such properties as permit of its adhering to them it would yet interfere seriously with the close contact of the water with the plates; whilst from its being in the form of a fine powder it would necessarily be a worse conductor of heat than if in a solid compact form. This action is not indeed readily observed in any boiler, because from the finely powdered state of the deposit the currents caused by blowing-off the boiler remove the powder also at the same time. Whatever may be the mode of action, it appears to be ascertained by experience that the presence of this fine floury precipitate in the water has the effect of preventing that intimate contact of the water with the plates, which is essential for carrying off with sufficient rapidity the heat communicated to the plates from the fire; so that although they may not be made actually red-hot, they become sufficiently overheated to lose a portion of their tenacity; and a bulging of the plates under pressure may ensue, which might lead to an explosion, although at the time there is no deficiency in the supply of water in the boiler.

One instance of the above action was observed in a double-flue boiler internally fired, near Birkenhead, which was fed with well-water and worked at 40 lbs. pressure; the furnace crowns were found repeatedly to give way and become bulged downwards, although they were made of the best boiler-plate and stayed to the boiler shell, and had not been exposed to shortness of water; it was found on examination that the water of the boiler was charged with

this fine floury precipitate. In another case of some single-flue boilers internally fired, near London, the furnace crowns failed repeatedly in the same way, the plates becoming bulged downwards; and here again the boilers were found to contain a considerable quantity of fine floury precipitate, the analysis of which showed 73 per cent. of carbonate of lime. In the case of several plain cylindrical externally-fired boilers, near Ruabon, a similar succession of failures occurred by the plates giving way over the fire, although made of the best boiler-plate; and this fine floury precipitate was found in the boilers, containing as much as 75 per cent. of carbonate of lime. The plates in this instance were $\frac{3}{8}$ inch thick, and the boilers $5\frac{1}{2}$ feet diameter, working at a pressure of 40 lbs. per inch.

The foregoing examples illustrate the importance not only of freeing boilers entirely from incrustation, but also of rendering harmless the impurities in the water, and preventing them from so thickening the water in contact with the heating surface of the boiler plates as to interfere with the due escape of the globules of steam from the surface of the plates. This object the writer believes is accomplished in a ready, inexpensive, and effectual manner, by the plan that forms the subject of the present paper, which is the invention of Mr. William Whittle of Birmingham; it requires no extra attention after being applied to a boiler, and has the advantage of increasing considerably the steam-producing power of the boiler, as well as its safety in working. This is effected by maintaining a very active circulation of the water over the heating surfaces, which not only prevents the formation of incrustation upon the plates, but collects to a very great extent the loose matter floating in the water, depositing it in the bottom of a lining or mud collector, and also removing from the plates any incrustation previously formed. The mud is thus separated from the water and rendered harmless by simply mechanical means; but in the case of using chemical means by employing boiler "compositions," the mud is dissolved and continues mixed up throughout the water, which consequently becomes so much thickened as to cause injury to the boiler by overheating of the plates. When large quantities of boiler

composition are employed, and regular blowing-off is neglected, as is too frequently the case, the water in the boiler becomes sometimes nearly as thick as gruel; and thus overheating of the plates is continually the consequence, although it may only occasionally be to such an extent as to be perceived by the occurrence of an accident.

In Figs. 1 to 8, Plates 12 to 16, is shown the application of the plan to different classes of boilers. Figs. 1 to 4 are longitudinal and transverse sections of plain cylindrical externally-fired boilers; and Fig. 8 is a vertical section of an upright boiler heated by puddling or mill furnaces. The lining or mud collector A is placed loosely inside the boiler, and extends throughout the entire lower half of the externally-fired boilers, Figs. 1 to 4, reaching nearly up to the ordinary water level, with a uniform space of about $2\frac{1}{2}$ inches left between the boiler shell and the lining, for the circulation of the water. The plates forming the lining, $\frac{1}{8}$ inch thick, are fitted closely together, and held in their places by studs I I, shown to a larger scale in Fig. 6, Plate 15; these are placed about one foot apart, and are made with solid collars upon them, whereby the uniform distance of the lining from the boiler shell is preserved. The lining plates are secured by cotters on the inside, so that any portion can be readily removed, whenever desired, for the purpose of examining the boiler plates at any part. For the circulation of the water, openings B B are made in the bottom of the lining, Figs. 1 and 2, or a single long slot C, Figs. 3 and 4; in the openings B B are fixed short tubes, and along the edges of the slot C the lining plates are turned up to some height, so as to prevent the mud that collects inside the lining from passing out through the openings with the circulation of the water; and in the upright boiler, Fig. 8, the lining is turned up round the centre flue for the same purpose.

The effect of adding the lining inside any boiler is that a very active circulation of the water is produced in the direction shown by the arrows; the water in the narrow space between the lining and the boiler plates becomes heated by contact with the heating surface of the plates, and forms a strong and continuous rising current,

which carries up the globules of steam as fast as they are formed, together with all the earthy matter that has been precipitated by the evaporation of the water, and delivers them on the surface of the water within the lining. In the comparatively quiescent water inside the lining, the earthy precipitate then settles down to the bottom of the lining, where it remains harmless in the form of soft mud, which never comes in contact with any part of the boiler heating surface, and is either got rid of readily by blowing-off at regular intervals, or is even allowed to accumulate for a considerable time without risk of injuring the boiler or interfering with the generation of steam. The formation of hard incrustation is entirely prevented, and the boiler plates are kept clean; and the water continuing also comparatively clear, the heat is consequently taken up from the flues with considerably greater rapidity than in ordinary boilers, in which the water is thickened with an accumulation of mud and the plates are coated with incrustation.

Although frequent blowing-off is to a great extent a means of getting rid of the impurities in the water, it is not only an expensive method on account of the waste of heat thereby occasioned, but the necessity for blowing-off increases the risk of injury to the boiler, by leaving it more dependent upon the constant attention of the stoker. Though an ordinary boiler may be frequently blown-off partially, the quantity of mud discharged by this means bears but a small proportion to that which is still contained in the water remaining within the boiler; for neither can blowing-off act generally over the surface of the bottom of the boiler, nor does the constant ebullition allow the fine particles to subside sufficiently to be carried away with the blowing-off, in the parts of the boiler most exposed to the fire. But with the use of the lining, the great body of the water in the interior of the lining is not in a state of active ebullition, but remains comparatively quiet; and thus a large quantity of mud is allowed to subside within the lining, which in ordinary boilers would continue floating in the water. This has been invariably found to be the case in the working of boilers fitted with the lining; and for the purpose of fully testing the action, some of the boilers have been kept in constant work day and night for more than two months, with feed water containing a large proportion of

earthy matter, and without blowing-off during the time; on subsequent examination the boiler plates were found to be clean and free from incrustation, while a large accumulation of soft mud had collected in the interior of the lining. In some instances of very bad water, where the boilers were blown off regularly three times a day, a large collection of mud was found to have taken place within the lining at a distance from the blow-off pipe, in addition to the portion blown off; and this would otherwise have remained floating in the water, or else would have settled upon the bottom plates of the boiler.

The quantity of loose mud requiring to be removed from the lining is so much in excess of the quantity to be removed from an ordinary boiler, as to prove clearly the value of the lining in separating the deposit from the water. The action of the lining shows indeed how great is the amount of solid matter that ordinarily remains floating in the water of a boiler or becomes deposited in the form of hard incrustation on the plates; and by being allowed to accumulate inside the lining upon surfaces that are not in contact with the heating flues nor exposed to strong currents of the water, the deposit is rendered perfectly harmless. Not only does the rapid circulation of the water over the heating surfaces prevent the formation of any incrustation upon the boiler plates, even when using very bad water, but in boilers previously incrusted with a considerable thickness of scale the application of the lining has resulted in the gradual and complete removal of the incrustation, the scale being loosened and washed over in fragments of considerable size into the inside of the lining.

Considerable economy of fuel is found to result from the more perfect communication of heat to the water in the boiler, consequent upon the clean heating surface and the continuous active circulation effected by the lining. Experiments have been tried with a plain cylindrical externally-fired boiler to ascertain the effect of the lining in producing economy of fuel, and it was found that the evaporative duty was increased by the use of the lining in the same boiler from $7\frac{1}{2}$ lbs. to 9 lbs. of water evaporated per lb. of coal, showing an economy in fuel of 17 per cent.: the total consumption of coal in each experiment being 1000 lbs.

An important advantage obtained by the use of the lining is that in the event of the water falling below the proper level, as shown in Fig. 3, Plate 13, an artificial level is maintained against the heated sides of the boiler as high as the top of the lining, in consequence of the continuous circulation between the lining and the shell. This protects the plates from becoming overheated as in ordinary boilers when the water is low, and greatly reduces the danger arising from temporary shortness of water.

In an internally-fired boiler, as shown in Fig. 5, Plate 15, the lining is required to be placed round the internal flue, leaving the same space as before for circulation of the water between the lining and the flue plates, with a continuous longitudinal opening along the top and bottom of the lining. This will have the effect of preventing any deposit from forming on the top of the fire-flue, and will preserve it from getting overheated and bulging down in the event of shortness of water; and it has been found by trial on a small scale with an experimental boiler that the strong circulation thus maintained is capable of making the water rise and flow over the top of the fire-flue, even when the water level has sunk as low as the level of the firebars, as shown in Fig. 5.

Another advantage attending the use of the lining is that the feed water is prevented from coming into direct contact with the heated boiler plates, the feed-pipe being introduced within the lining, as shown at D in Figs. 1 to 4; the feed water consequently becomes thoroughly mixed with the rest of the water and of uniform temperature with it, before reaching the plates of the boiler. This prevents the unequal contraction of the plates that occurs when the cooler feed water impinges direct upon them, as at E in Fig. 7, Plate 15, which has so injurious an action by causing extra strains upon the boiler seams.

In conclusion, the chief reasons of the value of the boiler lining are that it offers a quiet collecting place for all impurities, where so little heat can reach them that they are rendered harmless and prevented from caking upon any surface to such an extent as to require force for detaching them. At the same time, in consequence of the whole of the circulation being compelled to take place through

the narrow space between the lining and the boiler heating surfaces, the currents over these surfaces are so much quickened that they are caused to act mechanically in removing any old deposit from the plates, while also preventing any new from forming.

Mr. Addenbrooke said that at his own works at Darlaston he had now had the boiler lining in use for two years and a half in a plain cylindrical boiler, which was fed with very bad water containing a great quantity of lime, the water being drawn from an ironstone pit. Before the lining was applied, the inside of the boiler was coated with a thick incrustation from previous working; but after the boiler had been at work for a short time with the lining, the scale began to come off in pieces, which were carried over and deposited inside the lining. The loosening of the scale and the power to carry it over in large pieces into the mud collector were due to the greatly increased strength of current consequent on the whole of the circulation having to take place in the narrow space between the boiler shell and the lining. Since then the boiler had gone on working for considerable lengths of time without blowing-off at all, and on the occasions of cleaning the boiler it was found that the deposit had accumulated entirely inside the lining, and that there was no incrustation whatever upon the boiler plates, which were now clean and black like new plates, although they had not been scaled in the usual way with hammer and chisel. The boiler was at a colliery and roughly worked, so that there had not been the means of accurately ascertaining the saving in fuel consequent upon the use of the lining; but it had been found that the boiler made much more steam than before, and he knew that a considerable economy of fuel had been effected.

Mr. J. B. Fenby enquired whether any attempt had been made to apply the lining to Galloway boilers, in which he believed the incrustation was found to be particularly liable to settle in the cross

tubes; and it would therefore be very advantageous if this could be prevented by the application of the lining, though he feared there would hardly be room inside the cross tubes to carry the lining through them.

Mr. WHITTLE said the lining had not been applied to Galloway boilers on that account; and for the same reason it had not been applied to multitubular boilers, the tubes being brought so close to the boiler shell that there was not room left to get the lining in between. The lining had not yet been applied to any boilers with internal flues, except for the purpose of experiment.

Mr. SAMPSON LLOYD observed that it was well known a vessel placed inside a boiler would collect deposit from the water, on account of its affording a quiet place where the deposit could settle down in still water; he remembered collecting pans being extensively applied for the purpose in boilers as much as thirty years ago, and had no doubt many of them still continued in use, as they were found to answer admirably in collecting the deposit. In those cases the collecting pan was always placed with its edge a little above the water level in the boiler, so that the mud rising to the surface of the water as it boiled, flowed over into the pan and deposited itself inside. In the same way he considered that if the boiler lining now described were carried up a little above the water level, instead of terminating as it did a little below, it would collect the mud still better than at present; but there could be no doubt about its answering well as a mud collector in its present form. There might be some economy of fuel, he thought, from the circulation being more rapid round the outside of the lining, and thus causing the steam to be given off more rapidly; and there certainly would be a saving from the boiler plates being kept perfectly clean, free from the drawback of incrustation. He considered the plan was well worth further trial, and hoped that experiments would be made to determine the actual amount of economy effected by the use of the lining.

Mr. F. J. BRAMWELL remarked that, in regard to the old plan which had been referred to, of placing collecting pans inside boilers to catch the mud, he remembered seeing many years ago Mr. Perkins' mode of showing the circulation of water in boiling, by placing in an

open-topped saucepan a lining at a distance of about an inch clear from the sides, with an opening at the bottom; and the current of water was then seen to ascend at the sides and pass down again in the middle of the vessel. That plan had been applied by Mr. Perkins at the time to steam boilers, by providing them with a number of pendant tubes, inside which the linings or circulators were placed. The plan now described in the paper appeared to combine the two principles of the circulators and the collecting pans, and had consequently the advantage over either of them separately: the lining inside the boiler ensured the efficient circulation of the water being maintained regularly, and at the same time rendered the mud harmless by collecting it in a separate internal vessel, and preventing it from becoming deposited upon the boiler plates.

Mr. E. B. Marten observed that, having had occasion to examine the interiors of a great number of boilers in the South Staffordshire district, he had frequently met with the pans that had been alluded to for collecting the mud, but they seemed to be entirely neglected, as he had almost invariably found them quite full of mud; when once full they were of course no longer of the slightest service, and they could only be of use if regularly emptied as soon as they had become full, which would require the boiler to be opened every time for the purpose. He had seen several boilers fitted with the lining described in the paper, and had made the experiments there mentioned respecting the action of the lining. The addition of the lining inside a boiler had attracted his attention in the first instance as a means of gaining good circulation; and he had made a trial of it in an ordinary plain cylindrical boiler, in order to ascertain whether such a boiler was really so much inferior in evaporative duty to a Cornish boiler as was generally considered. The result had been that the duty of the plain cylindrical boiler with the lining came much nearer to that of the Cornish boiler than he had expected; and if one reason for the good duty of the Cornish boiler was that the steam had not far to pass through the water, the lining in the plain cylindrical boiler produced the same effect, the steam being liberated easily while the water was boiling up and passing over the edge of the lining; and the lining rendered the boiler altogether better able

to absorb the heat of the fire, and allowed less to pass away to the chimney. He had also seen the effect of the lining in removing deposit from the boiler plates where it had previously been formed, the current of water clearing it completely away, and even carrying over pieces of scale, much larger than would be imagined, and depositing them inside the lining. In an experiment which he had tried upon this point with the small model exhibited of a plain cylindrical boiler, 24 inches long and 8 inches diameter, fitted with the lining and closed with a glass top so that the action in the interior could be distinctly seen, he had found that the current of the circulation was so strong as to carry over sand, pounded scale, and even small shot, which were thereby deposited inside the lining.

Mr. E. A. Cowper thought that, with respect to bringing the duty of plain cylindrical boilers nearer to that of Cornish boilers, the subject did not involve any question of the height that the bubbles of steam generated had to rise through the water; but it was simply a question of the most effective mode of applying the heat to the water. In an externally-fired boiler it was clear there must always be a considerable loss of heat by conduction and radiation into the brickwork of the flues, the fire itself being situated in the brickwork; but when the fire was put right into the water, as in internally-fired boilers, the greatest proportion of the heat was taken up by the water before the current came in contact with the brickwork; and any kind of boiler with the fire inside must therefore be more economical than a boiler with the fire outside. He could confirm what had been said about Mr. Perkins' experiment that had been referred to, illustrating the circulation of water in boilers, as he remembered seeing it at the time and repeating the experiment by placing a common flower-pot inside a saucepan; the circulator applied by Mr. Perkins to boilers did not however collect the mud, but only ensured the active circulation of the water.

Mr. J. Robinson enquired what provision was made for getting rid of the mud which collected in the bottom of the lining described in the paper; and whether it was removed without having to open the boiler for the purpose.

Mr. Whittle replied that in some of the boilers fitted with the lining the mud deposited inside the lining was got rid of by blowing-off at suitable times, without opening the boiler; the blow-off pipe was perforated with 5-8ths inch holes and was laid horizontally inside the lining along the bottom, as shown at F in Figs. 1 and 2, and when the blow-off cock was opened, the mud was blown out along the whole length of the lining. It had however been found that with the use of the lining there was very little need for blowing-off, as there was room enough in the bottom of the lining to contain the accumulation of deposit from four or five months' working without blowing-off; and the more usual practice therefore was to open the boiler periodically, and shovel the deposit out of the lining. In one case of a small boiler 6 feet long and 2 feet diameter, the mud had been allowed to accumulate in the lining for more than six months, during which time every particle of the scale previously deposited upon the boiler plates had been brought away from them; and on blowing-off at the end of that period, the whole accumulation of mud had been cleared out of the lining. There was indeed no danger of any injury to boilers fitted with the lining, even if the emptying were done only once in six months, as that appeared to be quite sufficient for getting rid of all the mud.

Mr. J. Robinson supposed the time of working without blowing-off would depend greatly upon the kind of water used; and if the water contained sulphate of lime, instead of carbonate, he presumed the boiler would have to be blown-off more frequently, in order to prevent the deposit from adhering to the lining.

Mr. E. A. Cowper concurred in thinking that more frequent blowing-off would be necessary in boilers working with water that contained sulphate of lime, because this was always found much more injurious to the boiler plates than any other deposit.

Mr. Whittle replied that it was not recommended to work boilers longer than was desirable from convenience before blowing-off or otherwise cleaning out the mud; and he thought in general cases two months would be a good time to allow a boiler fitted with the lining to go on working without emptying.

The PRESIDENT enquired what was the object of making the boiler lining with the longitudinal slot all along the bottom, instead of only the two or three openings originally provided in the bottom of the lining.

Mr. WHITTLE replied that the longitudinal slot had been adopted in order to allow of examining the state of the boiler plates all along the bottom of the boiler, without having to take out the lining plates for the purpose. It had also been found, with the separate openings previously used, that there was a quiet place left in the boiler bottom midway between the openings, where sediment could be deposited without being swept away by the current of water circulating through the rest of the space between the lining and the boiler shell; but with the longitudinal slot there was no place where any deposit could settle on the boiler plates.

Mr. WILSON LLOYD considered the plan described in the paper for preventing incrustation in steam boilers possessed many advantages rendering its application exceedingly desirable. It was a very simple plan for the purpose, and not at all an expensive one; and he should expect to find it would become extensively adopted, when its success was more generally known. He enquired what number of boilers it had already been applied to.

Mr. ADDENBROOKE said there were at present about twenty-five boilers fitted with the lining, all of which were plain cylindrical boilers; the one at his own works had been in use for more than two years and a half to the present time. The lining had at first been looked upon chiefly as a mud collector, and it certainly was extremely valuable in that capacity; but its greatest value was that it did not allow any incrustation whatever to become deposited upon the plates of a boiler, and if put into a boiler already incrusted it cleaned the incrustation off in large pieces, which were carried over and deposited inside the lining; the mud which accumulated inside the lining remained in a loose condition, as it was not exposed there to a sufficient heat to cause evaporation, and its solidification into a hard scale was consequently prevented from taking place. He was himself so fully satisfied of the success of the plan that he was

already extending its application to other boilers at his works, and intended to apply it to all of them; at the Stour Valley Nut and Bolt Works also, where it was in use in some of the boilers, he understood it was intended to be applied to the rest.

Mr. F. C. Perry said he had had one of these linings placed in a boiler at the Roughwood Collieries near Bloxwich, which had previously required opening every three weeks or month for the purpose of having the scale removed. After applying the lining, the boiler was kept at work for six weeks before emptying, and then the result was found which had been stated in the paper to be produced by the adoption of the lining: the boiler bottom was found perfectly free from incrustation, the scale that was on the plates at the time the lining was put in having all been removed, and deposited in the interior of the lining with a large quantity of soft mud. He was so satisfied of the advantages of the lining, that he had ordered one to be placed in another boiler at the same collieries, and intended to apply it to the whole of the boilers under his control, all of them plain cylindrical boilers; and he had no doubt of the advantage that would result from the adoption of the plan in every instance.

Mr. E. A. Cowper enquired what was the cost of applying the lining to a boiler.

Mr. Whittle replied that the cost depended on the size of the boiler; for a plain cylindrical boiler 30 feet long and 5 feet diameter the cost of applying the lining would be about £10, exclusive of royalty which was 35*s.* per 50 superficial feet.

The President observed that, as regarded the economy of fuel attributed to the use of the boiler lining, it was clear that any plan which would keep the heating surface of the boiler clean must result in economy of fuel: but that any increased facility for the circulation of the water or for the passage of the bubbles of steam through the water would result in economy, he could not suppose would be the case, because all the heat actually put into the boiler must show itself in the form of steam; the only source of economy would be the prevention of deposit on the boiler plates, and the cleaner the plates the more effective would be the heating surface.

Of the two distinct kinds of deposit that had generally to be dealt with in steam boilers, namely the sulphate of lime and the carbonate of lime, the latter floated more loosely in the water, and on sinking gradually to the bottom formed there a friable deposit; but the sulphate of lime usually adhered very closely to the surface of the plates throughout the water space of the boiler, more particularly at the part where the greatest heat was applied. The moment a particle of water was evaporated into steam, the solid matter which it contained, especially if sulphate of lime, adhered to the heating surface; but the statements given in the paper respecting the action of the lining appeared to show clearly that it was possible by a mechanical arrangement to alter the action of the deposit and prevent it from adhering to the boiler plates, and to clear it away from them entirely, thus keeping the heating surface free from calcareous matter. This was a very important fact to know, and one that he should be glad to find confirmed by the further application of the lining, which in its capacity of a mud collector must certainly be greatly superior to any of the ordinary plans hitherto in use; and if it continued to be found as successful as in the cases where it had already been applied, it was evident that it must become extensively adopted.

He proposed a vote of thanks to Mr. Addenbrooke for the paper, which was passed.

The Meeting then terminated; and in the evening a number of the members dined together in celebration of the Twenty-fourth Anniversary of the Institution.

TUNNEL VENTILATING FAN.

Fig. 7.
Longitudinal Section.

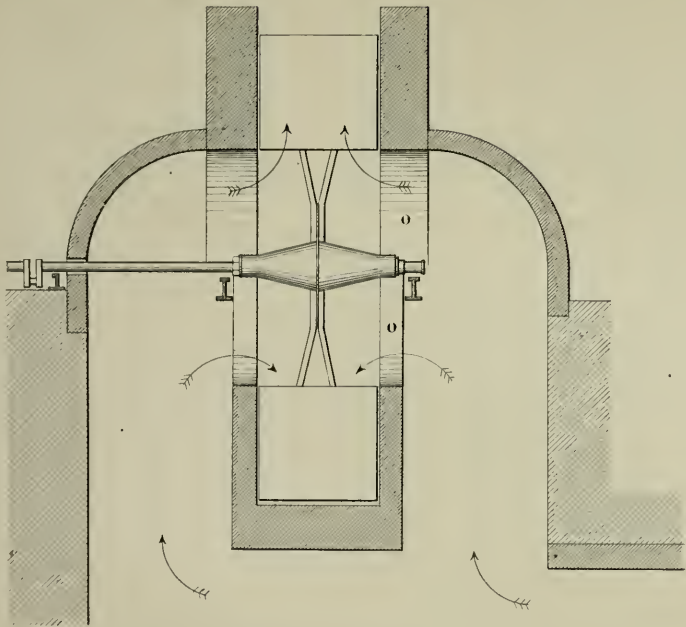
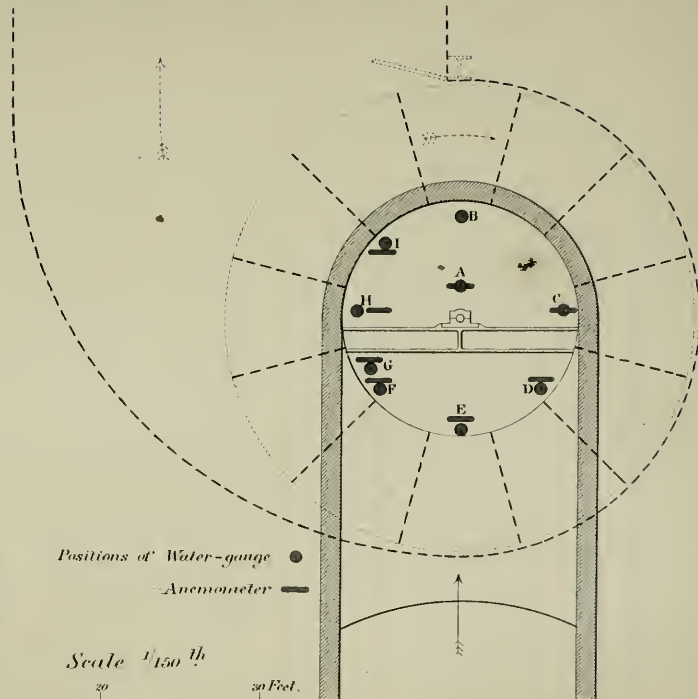
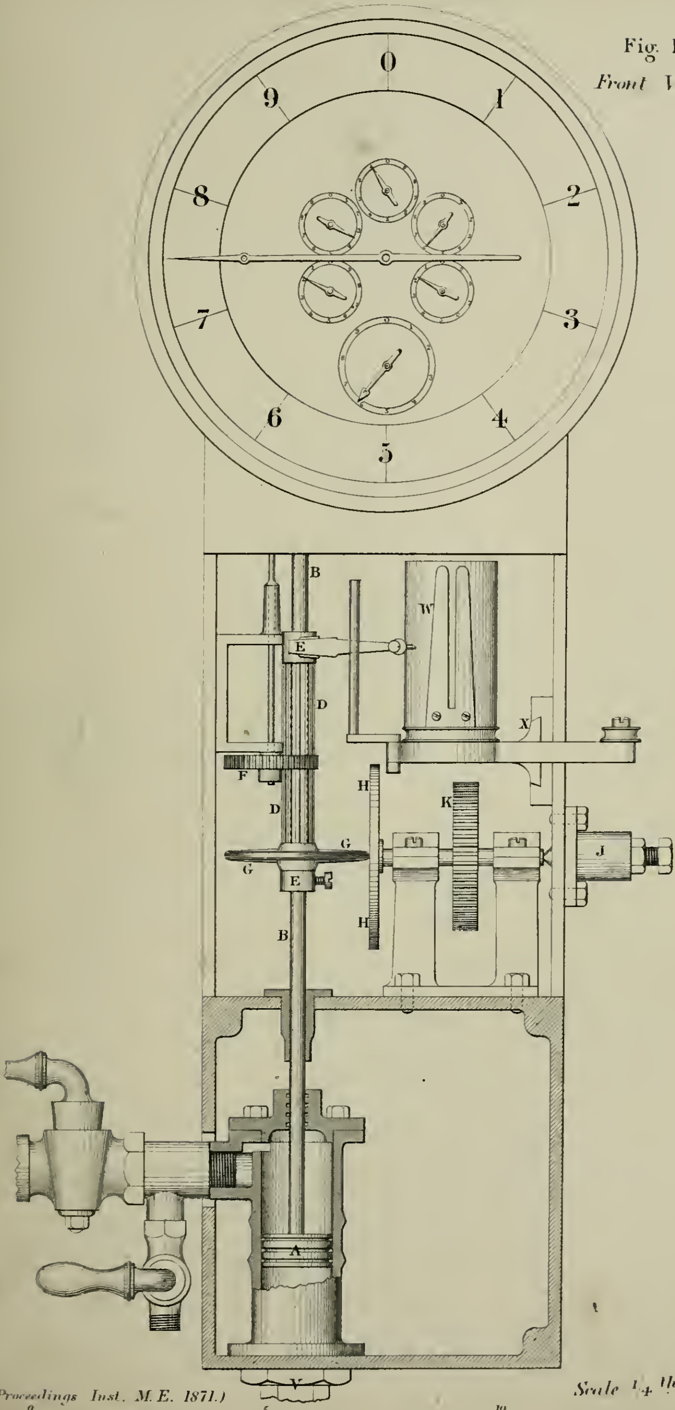


Fig. 8. *Elevation of Side of Fan-Case, showing positions of Water-gauge and Anemometer in the experiments.*



CONTINUOUS INDICATOR. *Plate 18.*

Fig. 1.
Front View.



(Proceedings Inst. M. E. 1871.)

Scale $\frac{1}{4}$*th*

0 5 10 15 *Inches.*

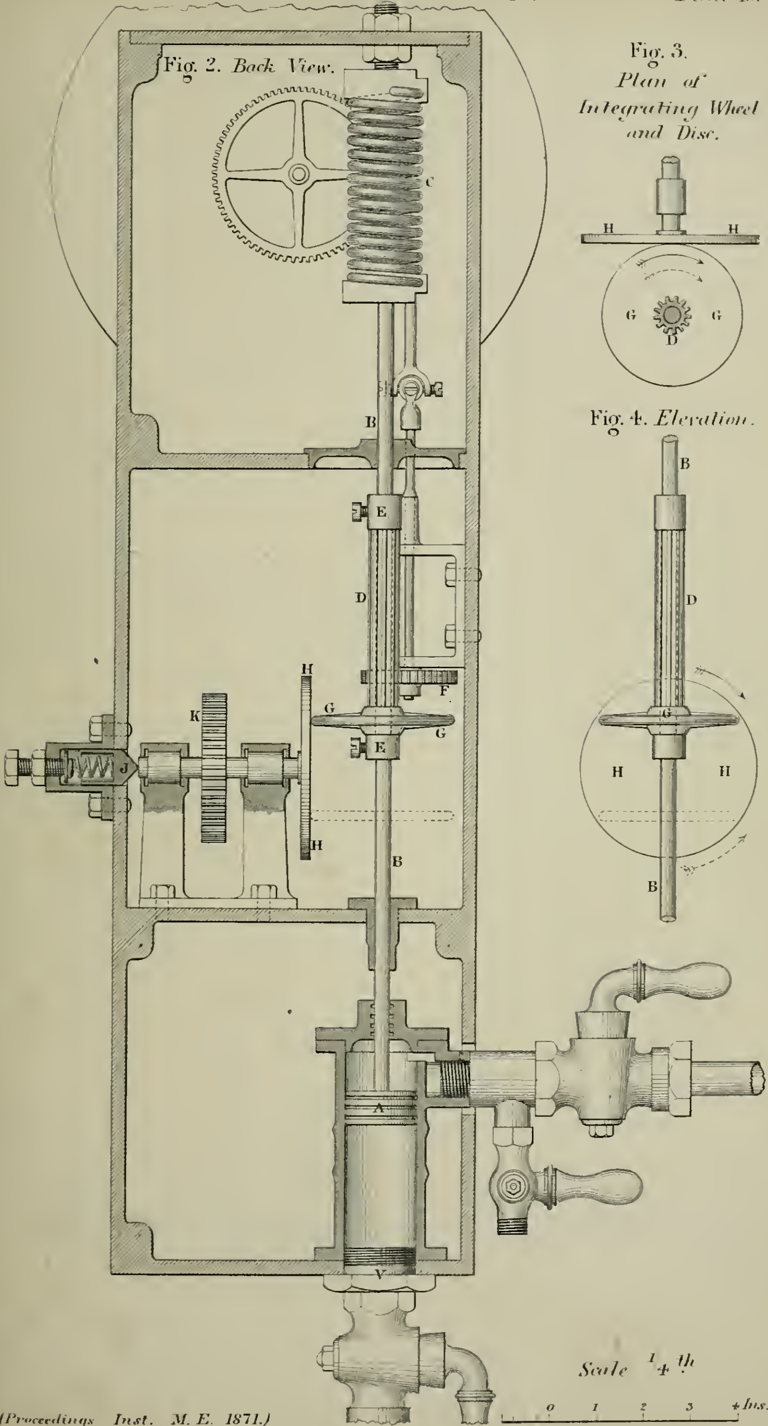


Fig. 2. Back View.
Fig. 3. Plan of Integrating Wheel and Disc.
Fig. 4. Elevation.
A
B
C
D
E
F
G
H
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K
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Scale 1/4 th
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Methods of driving the Disc-wheel.

Fig. 5. *Friction Bar.*

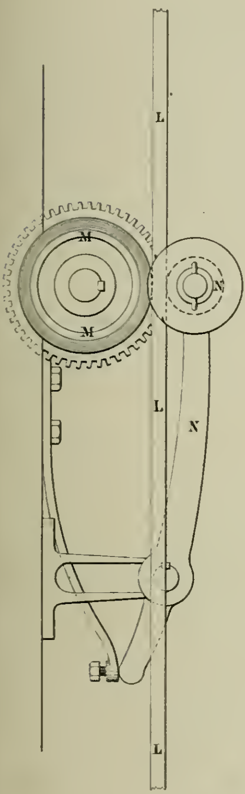


Fig. 6. *Cord.*

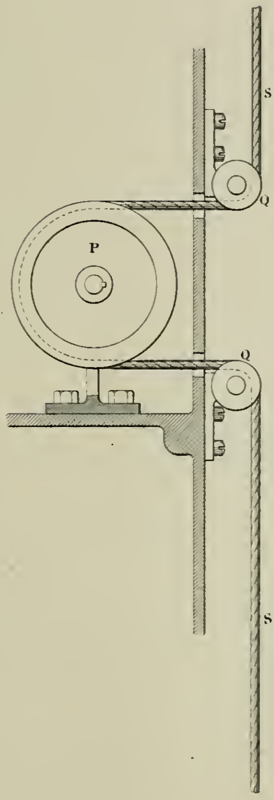


Fig. 7. *Rack.*

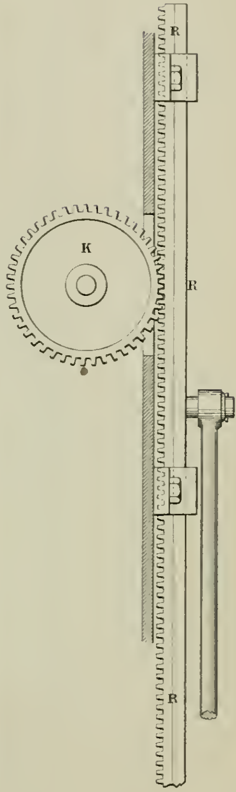
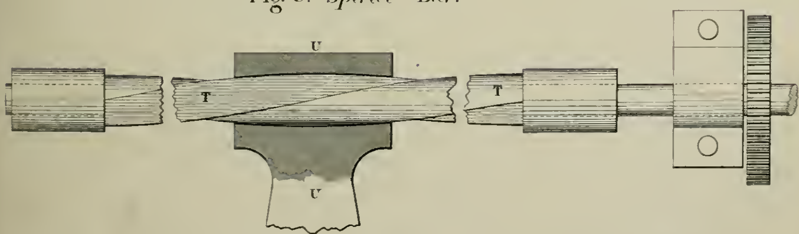


Fig. 8. *Spiral Bar.*



(Proceedings Inst. M. E. 1871.) *Scale 1/4 th*

0 5 10 15 *Inches.*

BREECH-LOADING RIFLES.

Prussian Needle Gun.

1848.

Fig. 1. *Loading.*

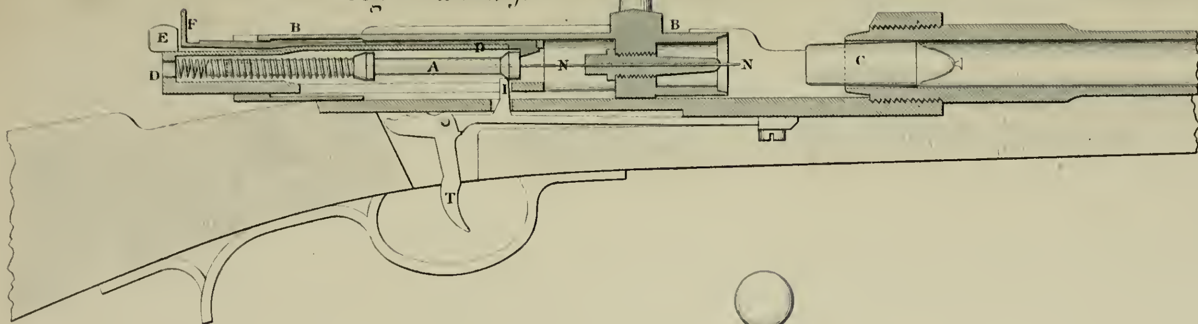


Fig. 2.

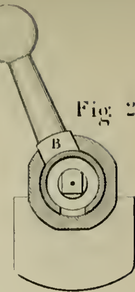


Fig. 3. *Firing.*

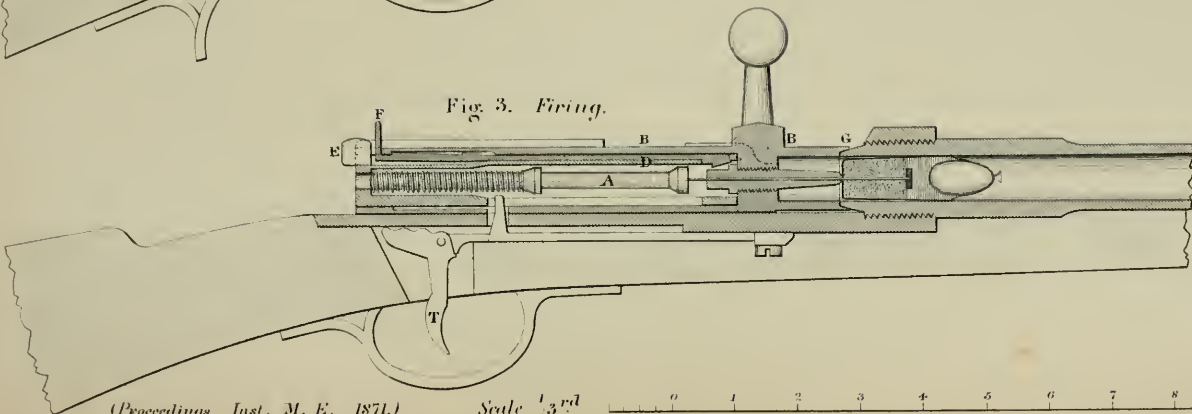
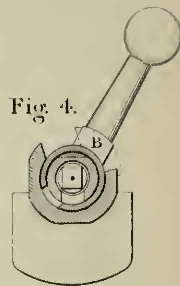


Fig. 4.

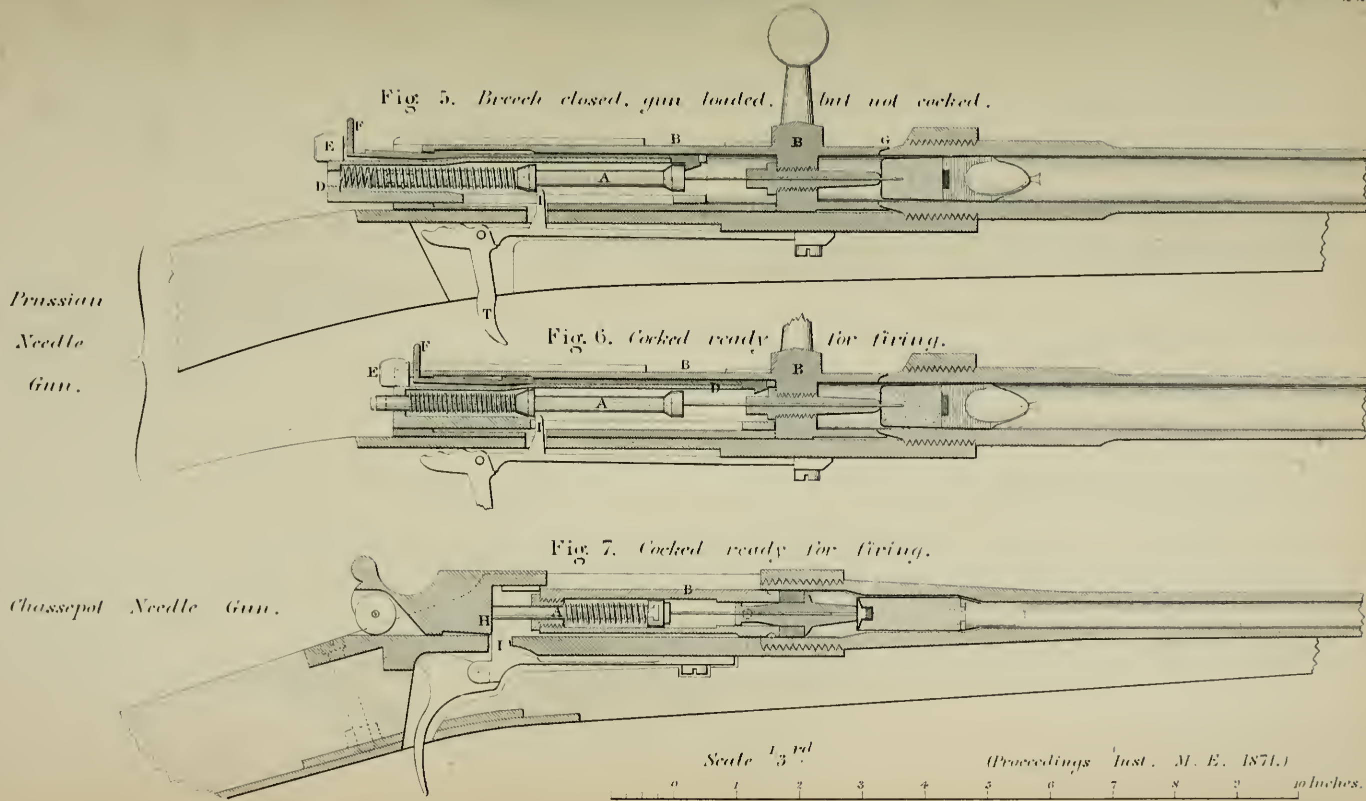


(*Proceedings Inst. M. E. 1871.*)

Scale $\frac{1}{3}$rd

0 1 2 3 4 5 6 7 8 9 10 Inches.

BREECH-LOADING RIFLES.



(Proceedings Inst. M. E. 1871.)

BREECH-LOADING RIFLES.

Chassepot Needle Gun.
1866.

Fig. 8. *Loading.*

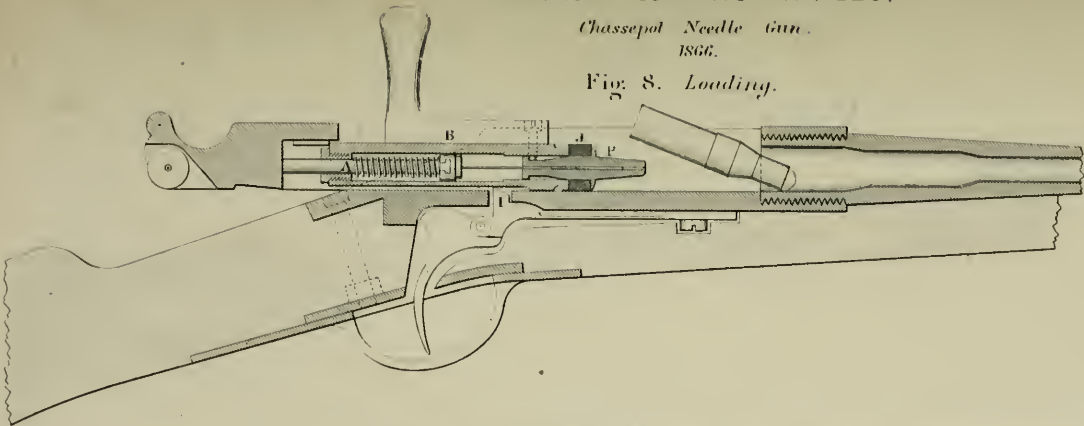


Fig. 9.

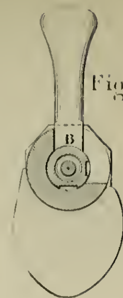


Fig. 10. *Firing.*

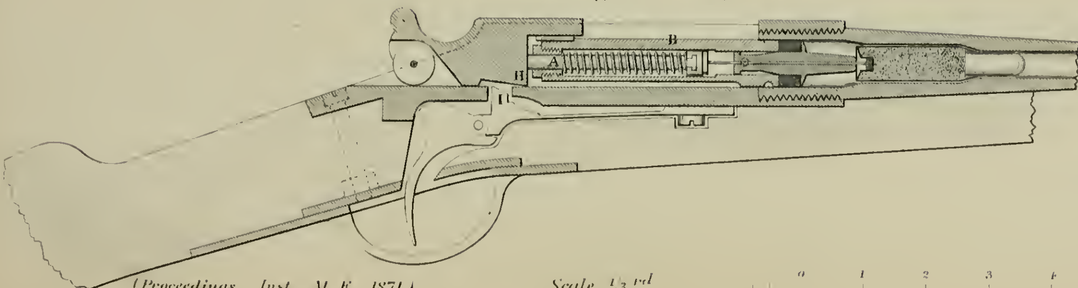
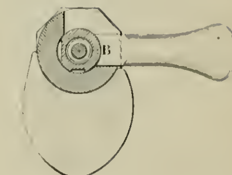


Fig. 11.



Scale 1/3 rd

0 1 2 3 4 5 6 7 8 *Inches.*

BREECH-LOADING RIFLES.

Double-Barrel Sporting Gun.
1858.

Fig. 12. *Loading.*

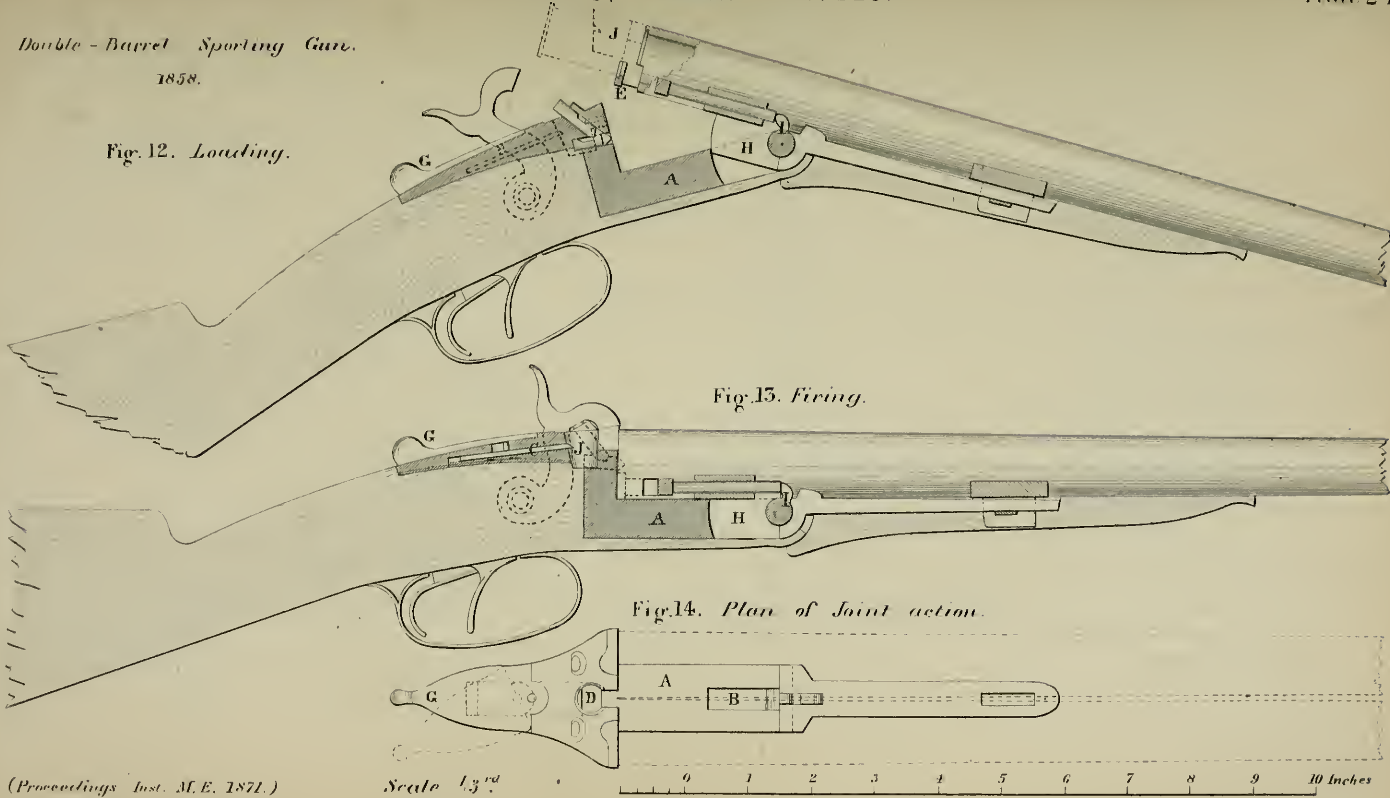


Fig. 13. *Firing.*

Fig. 14. *Plan of Joint action.*

(*Proceedings Inst. M.E. 1871.*)

Scale $1/3^{rd}$.

Snider.

1866.

Fig. 15. *Loading.*

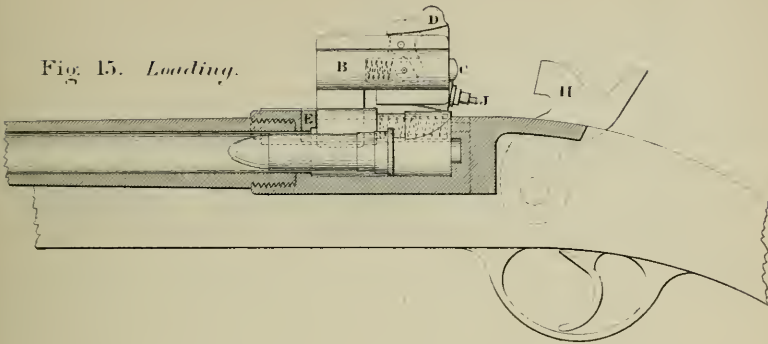


Fig. 16. *Firing.*

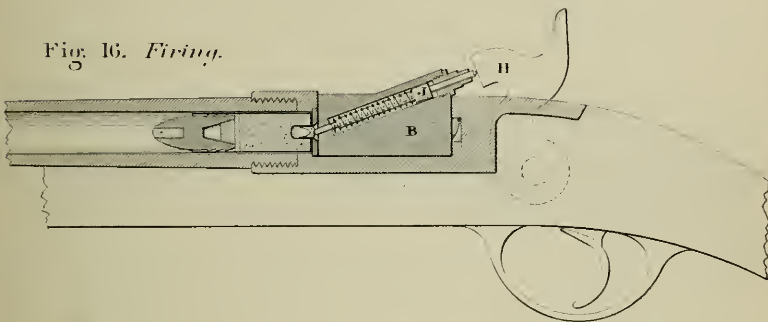


Fig. 17. *Extracting.*

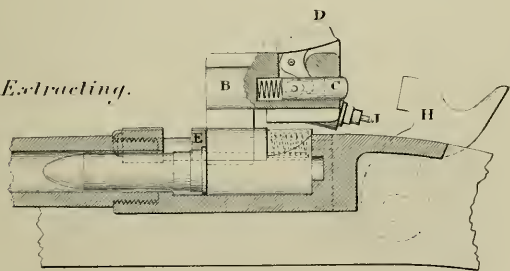


Fig. 18.

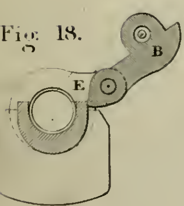


Fig. 19.

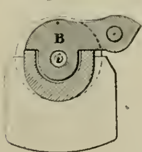
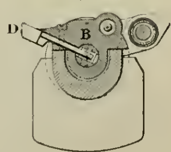


Fig. 20.



(Proceedings Inst. M. E. 1871.)

Scale 1/3 rd

0 1 2 3 4 5 6 7 8 9 10 *Inches.*

Albini - Braendlin.

1867.

Fig. 21. *Loading.*

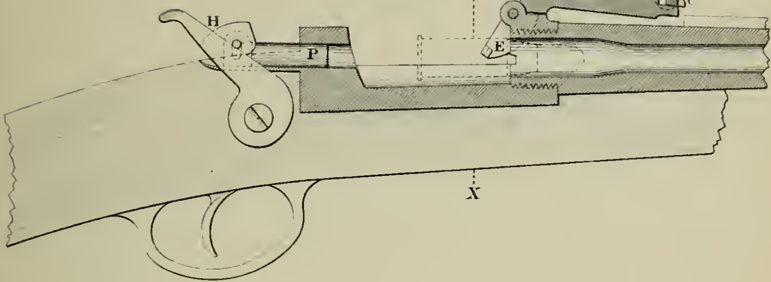


Fig. 22. *Firing.*

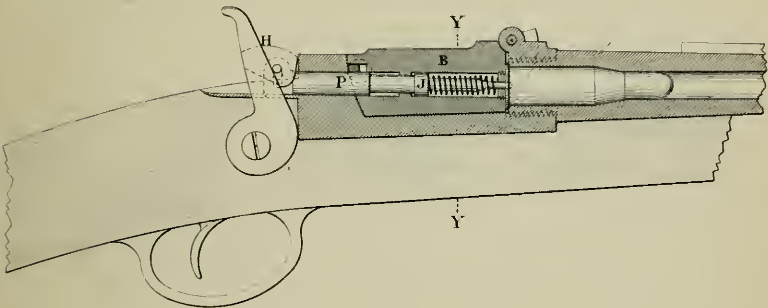


Fig. 23. *Plan.*

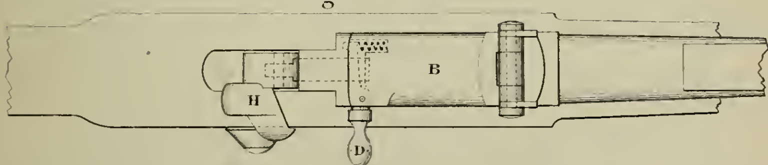


Fig. 24. *Section at* XX.

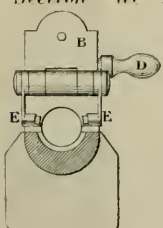
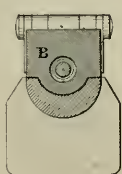


Fig. 25. *Section at* YY.



Scale 1/3 rd.

0 1 2 3 4 5 6 7 8 9 *10 Inches.*

Remington.

1867.

Fig. 26. *Loading.*

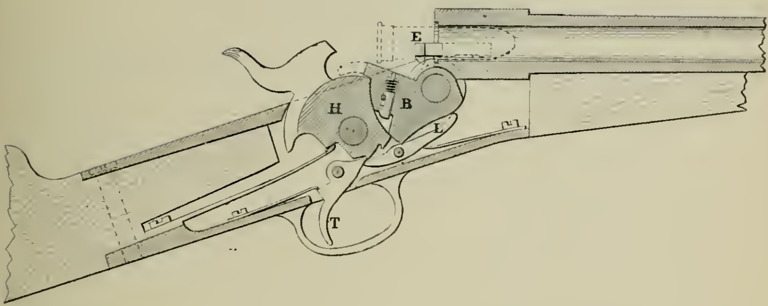


Fig. 27. *Firing.*

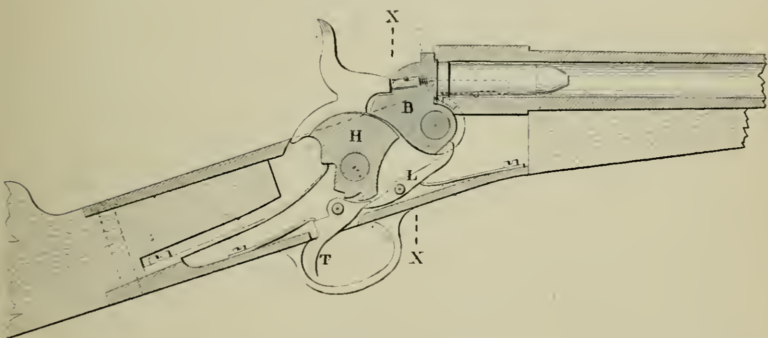


Fig. 28. *Plan.*

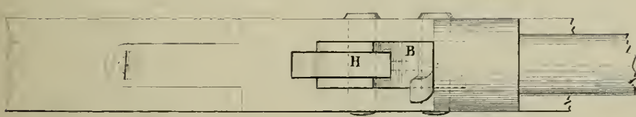
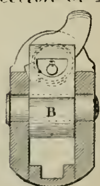


Fig 29.
Transverse
Section at XX.



Scale 1/3rd

0 1 2 3 4 5 6 7 8 9 10 *Inches.*

Werndl.

1867.

Fig. 30. *Loading.*

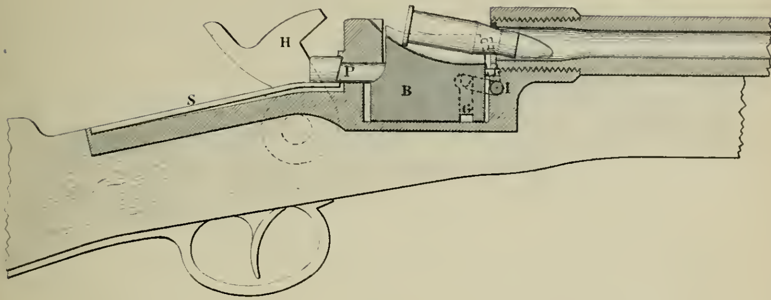
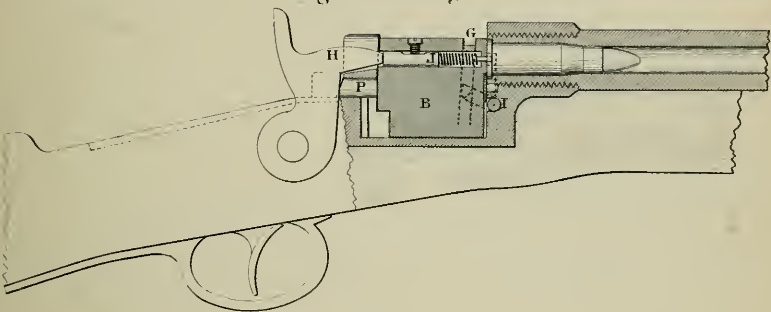
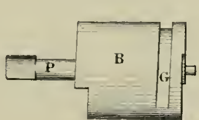


Fig. 31. *Firing.*



Elevation of Breech - Block.

Fig. 32.



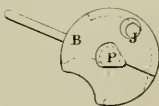


Fig. 33.

Fig. 34.
Extractor.

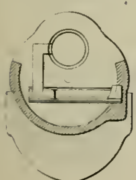


Fig. 35.
Breech Open.

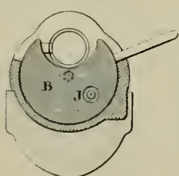
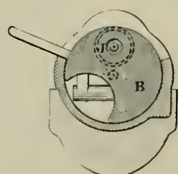


Fig. 36.
Breech Closed.



(Proceedings Inst. M. E. 1871.) *Scale 1/3 rd*

0 1 2 3 4 5 6 7 8 9 10 Inches.

BREECH - LOADING RIFLES.

Plate 29.

Henry.

1870.

Fig. 37. *Loading.*

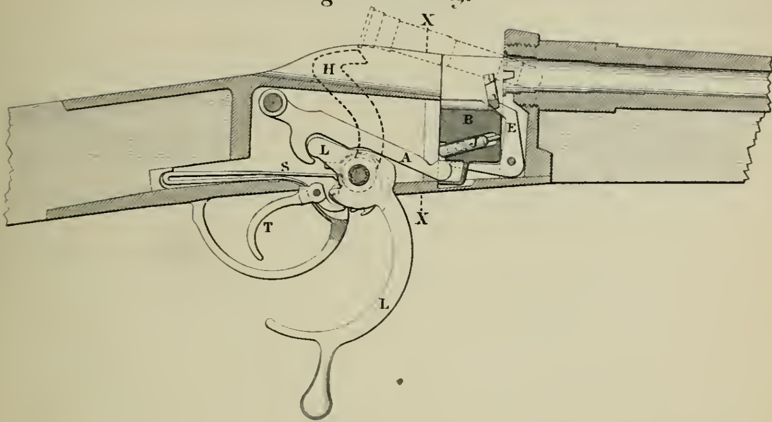


Fig. 38. *Firing.*

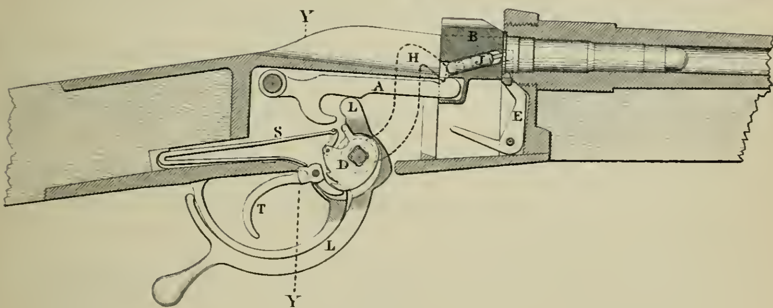


Fig. 39.
Transverse Section at XX.

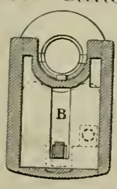
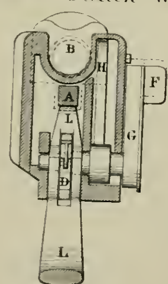


Fig. 40.
Transverse Section at YY.



(Proceedings Inst. M. E. 1871.) *Scale 1/3rd.*

0 1 2 3 4 5 6 7 8 9 10 *Inches.*

BREECH-LOADING RIFLES.

Soper. 1870.

Fig. 41. *Loading.*

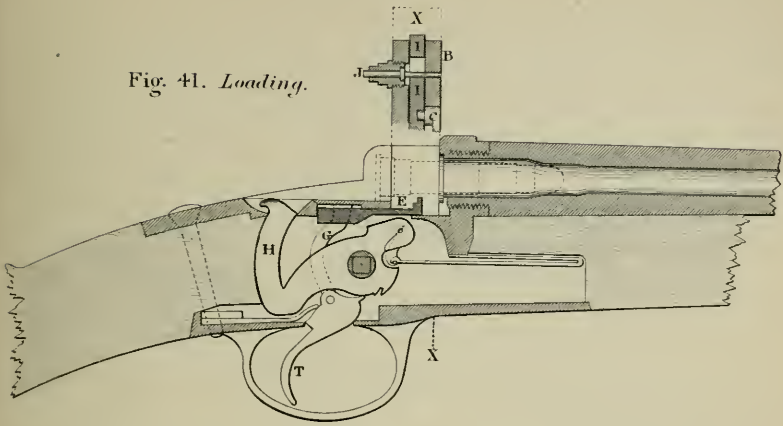


Fig. 42. *Firing.*

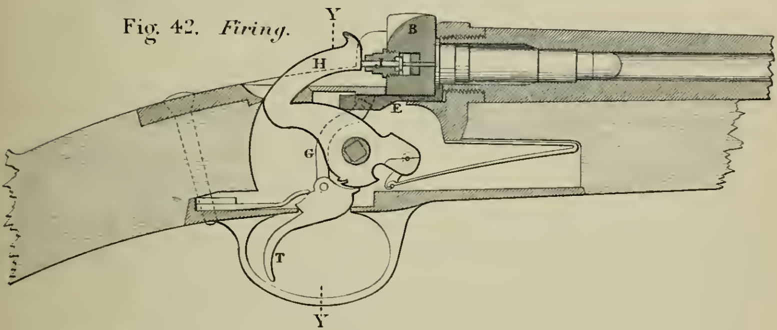


Fig. 43.

Section at XX.

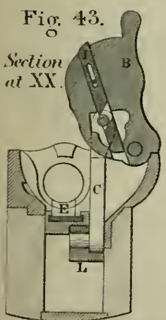


Fig. 44.

Breech-Block opening.

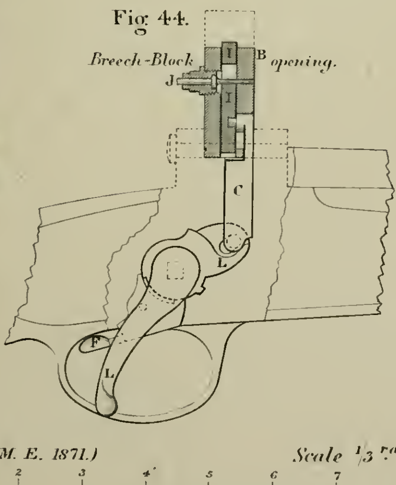
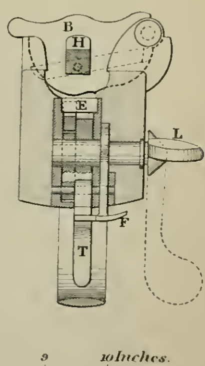


Fig. 45.

Section at YY.



(Proceedings Inst. M. E. 1871.)

Scale 1/3 rd

0 1 2 3 4 5 6 7 8 9 10 *Inches.*

Peabody.
1865.

Fig. 46. *Loading.*

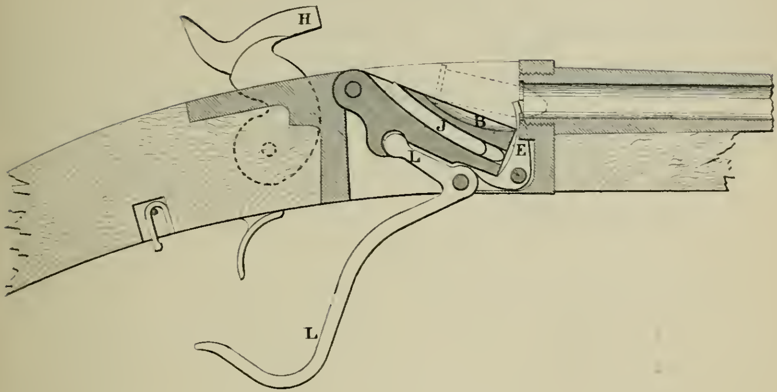


Fig. 47. *Firing.*

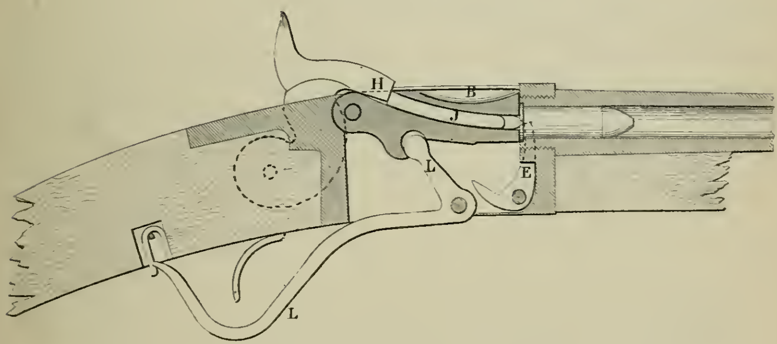
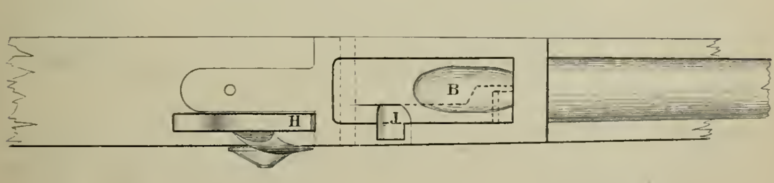
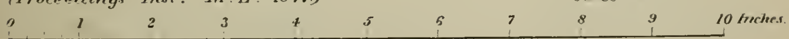


Fig. 48. *Plan, when cocked.*



(Proceedings Inst. M. E. 1871.) *Scale 1/3rd*



Martini.
1868.

Fig. 49. *Loading.*

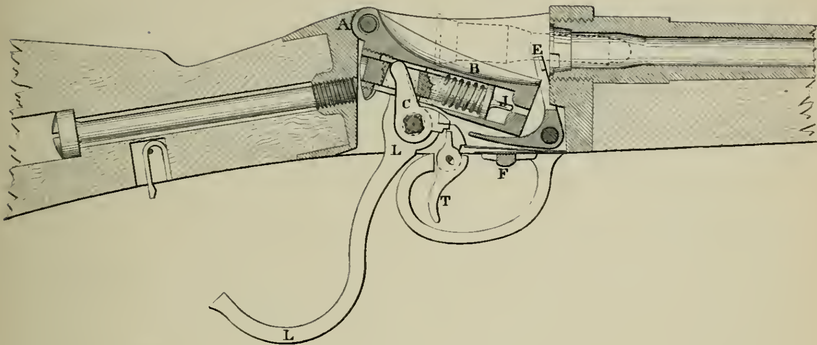


Fig. 50. *Firing.*

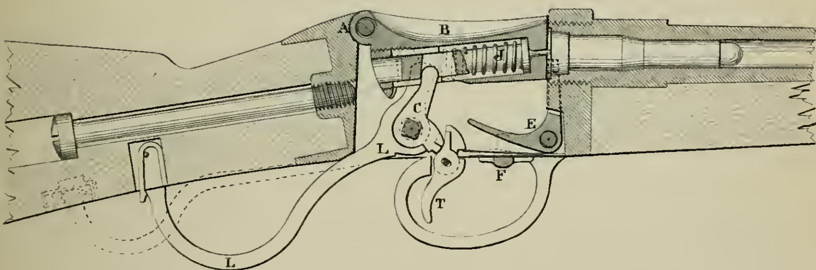


Fig. 51.
Transverse Section at XX.

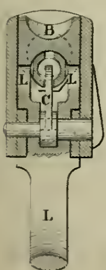


Fig. 52. *Cocked, and locked.*

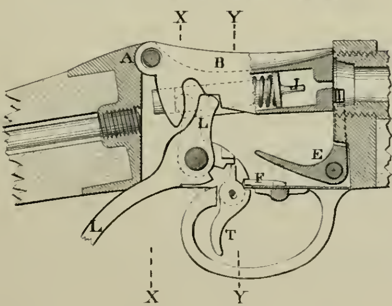
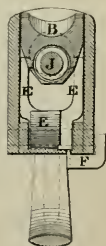


Fig. 53.
Transverse Section at YY.



(Proceedings Inst. M. E. 1871.) *Scale 1/3rd*

Martini.

Fig. 54. *Cocking and Firing action*

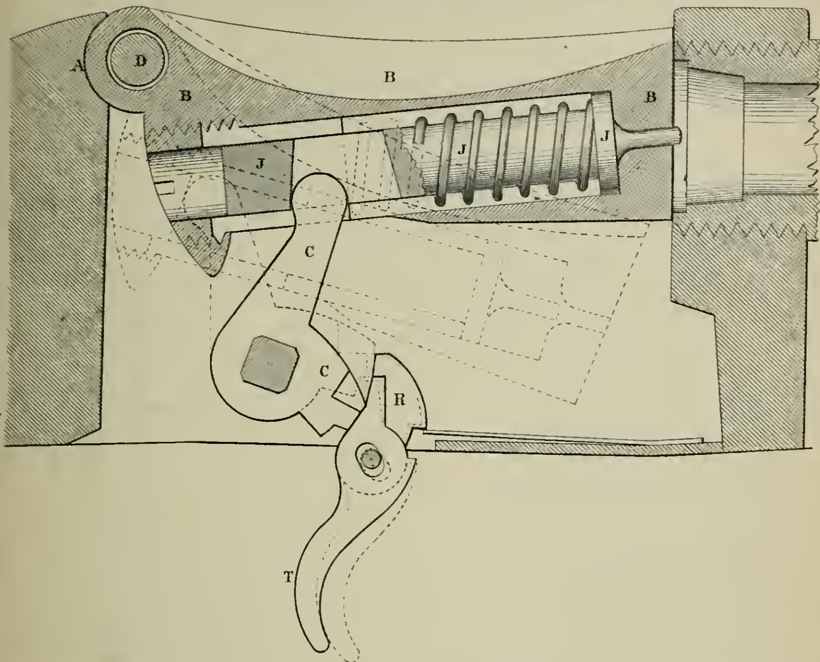
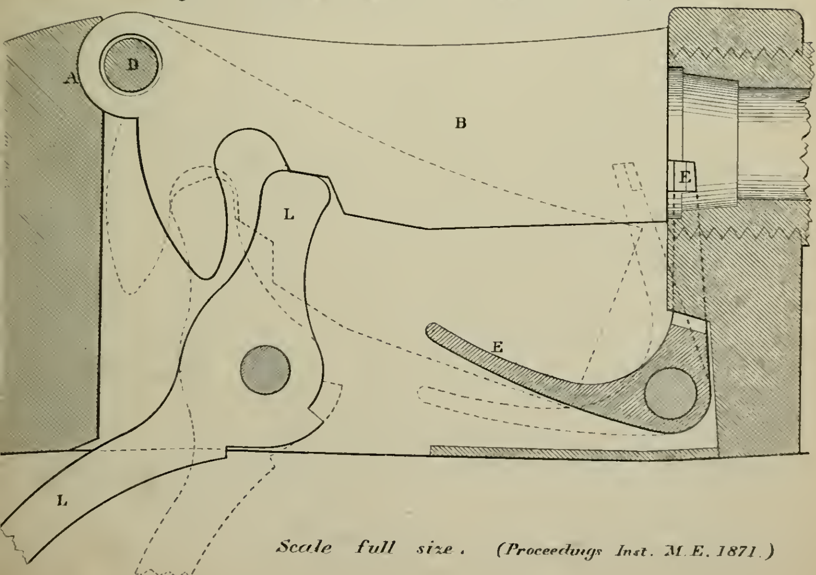


Fig. 55. *Breech-block and Extractor action*



Scale full size. *(Proceedings Inst. M. E. 1871.)*

Diagrams of Trigger action, Martini.

Fig. 56.

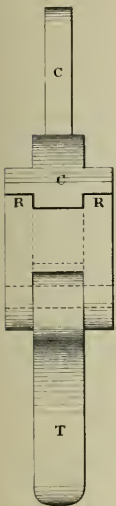


Fig. 57.

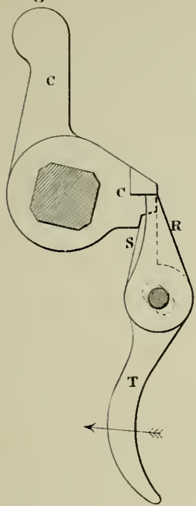


Fig. 58.

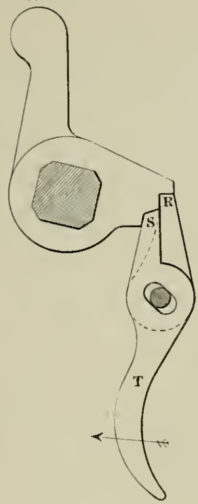
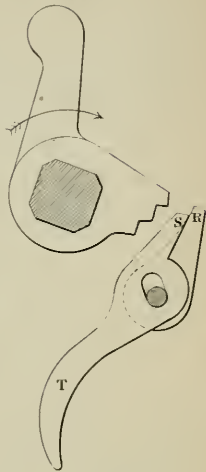


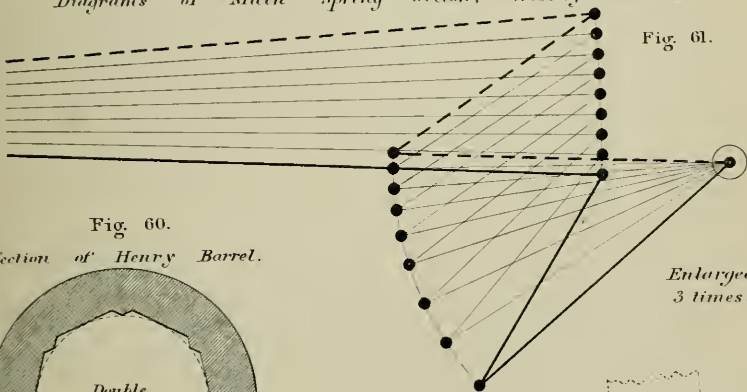
Fig. 59.



Full size.

Diagrams of Main Spring action, Westley Richards.

Fig. 61.



Enlarged 3 times.

Fig. 60.

Section of Henry Barrel.

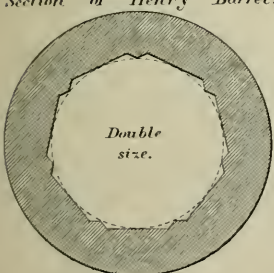
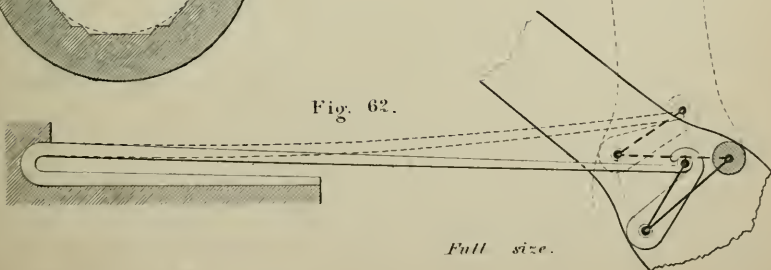


Fig. 62.



Full size.

BREECH-LOADING RIFLES.

Westley Richards.
1870.

Fig. 63. *Loading.*

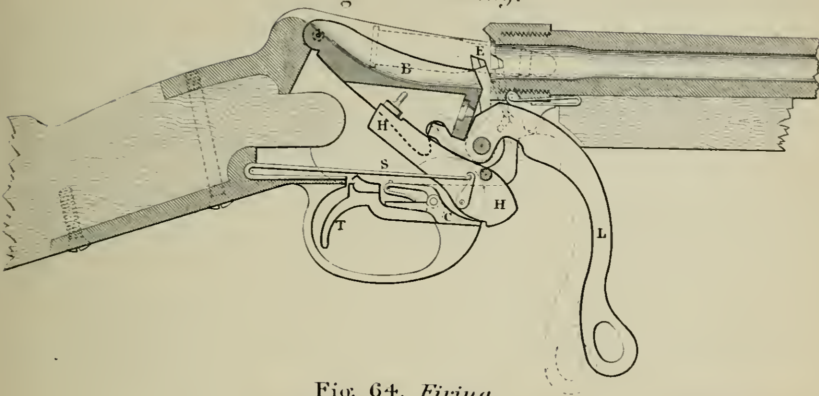


Fig. 64. *Firing.*

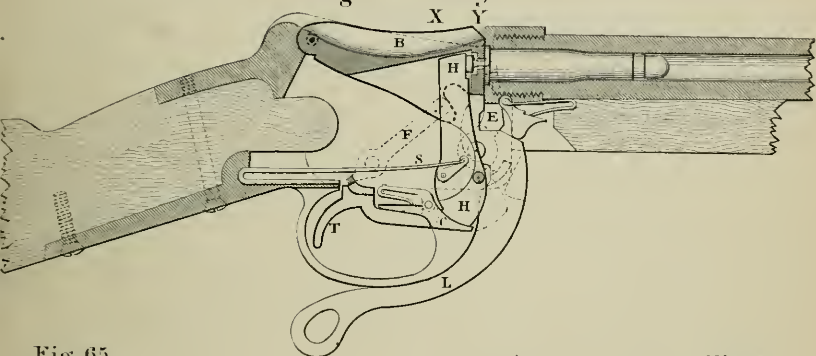


Fig. 65.
Transverse Section at X.

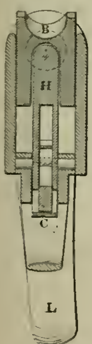


Fig. 66. *Cocked, and locked.*

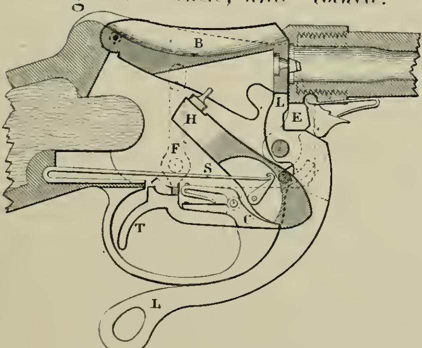
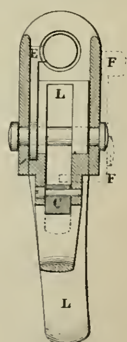


Fig. 67.
Transverse Section at Y.



Scale $\frac{1}{3}$ rd

Westley Richards.

Fig. 68. *Cocking and Firing action.*

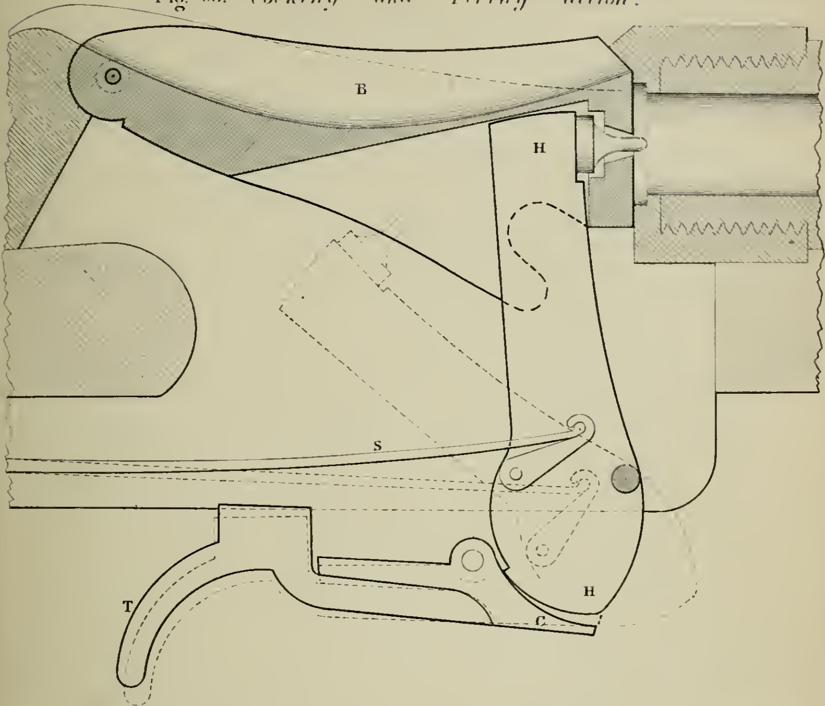
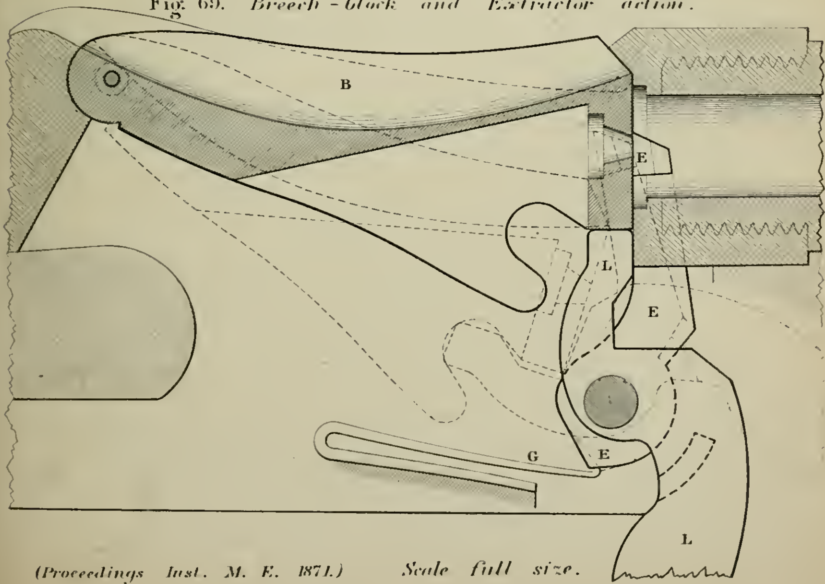


Fig. 69. *Breech-block and Extractor action.*



(Proceedings Inst. M. E. 1871.) *Scale full size.*

PROCEEDINGS.

27 April, 1871.

The General Meeting of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 27th April, 1871; John Ramsbottom, Esq., President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The President announced that the Ballot Lists had been duly opened, and the following New Members had been found to be elected:—

MEMBERS.

John Wolfe Barry, ...	London.
William Silver Hall, . . .	Nottingham.
John Hick, M.P., ...	Bolton.
George Horton, ...	London.
Pershouse Parkes, ...	Tipton.
James Platt, ...	Gloucester.
John Rigg, ...	Crewe.

ASSOCIATE.

John Patterson, ...	Manchester.

GRADUATE.

Ernest Charles Thurgood, . .	Birmingham.

The following paper was then read:—

ON THE MECHANICAL VENTILATION OF THE LIVERPOOL PASSENGER TUNNEL ON THE LONDON AND NORTH WESTERN RAILWAY.

By JOHN RAMSBOTTOM, Esq., President.

(*Supplementary Paper.*)

Since the last meeting of the Institution, at which a description was given of the large Ventilating Fan employed for clearing this tunnel of smoke and steam after the passage of locomotives (see Proceedings Inst. M. E. January 1871 page 22), further experiments have been made with a view to ascertain the vacuum produced by the fan at various positions in the central opening of the fan case; and the results of these experiments are given in the accompanying Table.

TABLE OF EXPERIMENTS.

Vacuum shown by Water-Gauge at different positions in entrance of Fan Case.

Speed of Fan, 45 revolutions per minute. Diam. 29 ft. 4 ins. Width 7 ft. 6 ins.

1 Position of Orifice of Gauge-Pipe. See Fig. 8, Plate 17.	2 Orifice pointing OUTWARDS.	3 Orifice pointing INWARDS.	4 Orifice *muffled*, pointing OUTWARDS.	5 Orifice *muffled*, pointing INWARDS.	6 Revolutions of Anemometer per minute.
	Inch.	Inch.	Inch.	Inch.	No.
A	0·70	0·70	—	—	170
B	0·30	0·50	—	—	—
C	0·60	—	—	—	Irregular
D	0·30	0·90	1·05	0·95	400
E	1·30	1·20	1·10	1·20	190
F	0·50	1·70	1·25	1·65	250
G	0·80	1·10	0·75	1·05	330
H	0·80	1·20	1·00	—	320
I	0·35	1·10	0·80	1·05	350

The mouth of a lead gauge-pipe of $\frac{1}{2}$ inch bore was placed in the nine positions shown by the black dots A to I in Fig. 8, Plate 17, in the central opening O O of the fan case, on the side nearest to the tunnel, Fig. 7. The other end of the pipe communicated with a water-gauge placed in the engine house, and the readings of this gauge are given by the figures in the table. The atmospheric pressure in the engine house during the working of the fan was previously compared with that of the air outside, and was found not to differ appreciably from it. The whole of these experiments were made while the fan was running at the regular working speed of 45 revolutions per minute.

The figures in the second column are the readings of the water-gauge when the mouth of the pipe was pointed directly outwards, from the fan, so as to face the current; those in the third column, when it was pointed directly inwards, towards the fan. The fourth column gives the readings when the pipe was muffled by a coarse cloth tied over its mouth, and was pointed directly outwards, from the fan; and the fifth column, when the muffled pipe was turned directly inwards, towards the fan.

The sixth column shows the number of revolutions made per minute by an anemometer placed in the positions shown by the black lines at A to I in Fig. 8. This instrument was of the kind recommended by Dr. Robinson, and consists of four hemispherical cups, attached to the extremities of two arms at right angles to each other, and revolving in a horizontal plane upon a vertical spindle, by the excess of pressure of the current of air upon their concave surfaces over that on their convex surfaces. The diameter of each of the cups is 2 inches, and they revolve in a circle of 12 inches diameter; on the vertical spindle is a tangent screw actuating the wheelwork of a small counter. No opportunity having occurred for testing this instrument on a perfectly calm day, or for comparing its readings with those of a known standard, the figures given in the table are simply the number of revolutions made by the anemometer in the different positions, and are considered only as indicating the relative velocities in the different parts of the current, with the fan running at 45 revolutions per minute.

The indicated horse power of the engine, whilst exhausting the tunnel, amounts to

126·0 horse power with the fan running at	43	revolutions per minute.
133·3 ,, ,, ,,	44	,, ,,
133·9 ,, ,, ,,	45	,, ,,

When the outlet at the top of the fan case was closed, and therefore no useful work was being done, the indicated horse power expended in driving the engine and fan was as follows, the work done by the fan being then confined to fluid friction, skin friction, and probably the flux and reflux of air through the central openings of the fan case:—

32·0 horse power with the fan running at	43	revolutions per minute.
33·8 ,, ,, ,,	44	,, ,,

The President observed that the further experiments now described, which had been suggested by the remarks in the discussion at the previous meeting, had had to be made in a place that was necessarily dark, and the regular working of the train service had been carried on all the time as usual, which caused the fan case and its approaches to be filled continually with black smoke; so that considerable difficulties had presented themselves in the way of getting at scientifically accurate results. Practically however he believed the results arrived at were sufficiently near the truth; and the conclusion he drew from the further facts thus elicited was that no material improvement could be made in this ventilating fan, except in regard to the concentric half of the fan case. From the figures given in the Table it was evident that the discharge from the fan was exceedingly small round the concentric half, and it was only on approaching the spiral portion that any large quantities of air were delivered, thus showing that it would have been better if the spiral casing had been continued round the concentric half also, as had been originally intended, so as to allow

of a free discharge round that portion of the circumference. It should be borne in mind that ventilating fans might be divided into two broad classes, which might be termed "intensity" fans and "quantity" fans; and the present tunnel fan was emphatically one of the latter class, delivering a large quantity of air with a very slight degree of vacuum. With regard indeed to the actual amount of the vacuum, repeated experiments as to the degree of resistance due to the tunnel itself had fully confirmed the amount stated in the former paper (0·14 inch of water) as the vacuum caused by the tunnel resistance; which showed that if the tunnel itself were removed, and the fan were left to draw in the air direct from the atmosphere through the cross drift alone, there would be but little difference in the result as regarded either the quantity or tension of the air entering the fan case. He thought accordingly that a delivery round the entire circumference of the fan would be preferable for discharging the large quantity of air required, and therefore that the spiral form of case would be the best under such circumstances. This conclusion was not inconsistent with the results which had been arrived at in other experiments upon ventilating fans constructed on the Guibal principle for ventilating mines, where the degree of vacuum was much greater on account of the greater resistance of the mine passages, but where the quantity of air to be delivered was much less. In the case of the large Guibal fan of the same diameter employed for ventilating the Staveley collieries, which he had seen in operation, having the concentric casing and adjustable sliding shutter which were among the distinguishing features of that construction of ventilator, the quantity of air to be discharged at each revolution of the fan did not exceed about 1,700 cubic feet, and the concentric case was therefore not incompatible with that low delivery; but in the tunnel fan the quantity to be discharged at each revolution amounted to nearly 10,000 cubic feet. The apparently low duty of the latter fan, when considered in relation to its actual effect in ventilating the tunnel, was mainly to be accounted for by the great loss of power consequent upon the amount of obstruction offered to the air current after it had left the tunnel, the current being four times diverted at right angles

before it was discharged from the fan: once on entering the cross drift from the tunnel, a second time on turning up from the drift into the uptake to the fan, again on entering the fan case, and lastly on quitting the circumference of the fan. It was evident that by further increasing the resistance offered to the current, the tension of the air would be increased and the quantity discharged would be diminished in any given fan, until the extreme limit was reached when the resistance would be so great that there would be no discharge at all, and the fan case might then be made concentric all round. The results of the present experiments therefore, showing as they did the differences in the tension of the current at different parts of the central inlet of the fan case, had led him to the general conclusion that the spiral case was the proper form for at least a certain portion of the circumference; and that where the quantity to be delivered was large, the spiral should extend further round the fan, while for a smaller delivery the proportion of the concentric part of the case might be increased.

Mr. F. J. Bramwell enquired whether any explanation could be given of the circumstance that in the fan experiments now described the number of revolutions made by the anemometer in the different positions in which it was placed did not appear to bear any relation whatever to the amount of vacuum noted by the water-gauge in the same positions. For instance, with the highest vacuum of 1·30 inch (in column 2 of the Table) the number of revolutions of the anemometer was only 190 per minute; whilst in another position, with a vacuum as low as 0·30 inch, the anemometer made as many as 400 revolutions per minute.

The President replied that the apparent anomaly pointed out in the results of the experiments had taken him much by surprise, and he was at a loss to account for it, unless it arose from some local disturbance occasioned by the cross girder which carried the fan shaft. An anemometer of the construction employed in these experiments was of course open to the action of currents in any direction; and it had been found that there was a cross current passing along the horizontal girder, right across the opening of the fan case, as was shown in the Table of results by the greater degree

of vacuum at the point marked H on the expanding side of the fan case, than at the opposite point marked C on the concentric side. This was the only cause he could think of for the remarkable irregularities shown by the anemometer; and he could only give the results as facts which had been ascertained as carefully as was possible.

Mr. E. A. Cowper thought the principles deduced from the results of the fan experiments now described would be followed out in the most complete manner by making the fan case of a spiral form all round; for it was shown that with this large fan, delivering a large quantity of air with a very moderate degree of vacuum, the concentric half was inoperative as regarded any discharge of air, and the spiral half alone was effective. The more correct mode, he considered, of meeting variations in the quantities to be delivered, would be to adhere in all cases to a complete spiral round the entire circumference, and simply to vary the pitch or degree of opening of the spiral according to the delivery required in each particular instance. For an infinitesimal delivery this plan would give a spiral of infinitesimal opening, which would thus coincide with the concentric casing arrived at under the same condition by the other mode of viewing the subject. If a large quantity of air had to be delivered with a small degree of vacuum, the spiral would be made to open out rapidly; while on the other hand a small delivery with a great amount of vacuum would require a spiral of more gradual opening. The great advantage of the complete spiral casing was that all the vanes were then always equally effective throughout the entire revolution, and always doing their full share of the work, and the air was treated in the same way all round the fan, an equally free delivery being provided for it at every portion of the circumference. With that form of casing therefore, he considered, the greatest possible effect would be obtained from any size of fan, with the least amount of loss by eddies or regurgitations of the air.

Mr. A. Alexander concurred in thinking the spiral form was the right one for the fan case, and believed this had generally proved the best for all kinds of fans. The extreme instance however of a fan

working under a great pressure or vacuum but with an infinitesimal delivery could hardly be considered to bear upon the question of the spiral form of the casing, because the degree of opening of the spiral would then be so minute that the casing would practically be identical with a concentric one. A suggestion that occurred to him with regard to the construction of the fan itself was to curve the blades backwards, instead of making them radial as in the tunnel fan; the backward curving of the blades he believed had been found very advantageous in other cases, particularly where a large quantity of air was required to be delivered. He thought also it would be an improvement to make both the fan and the casing of a taper form, narrowing in width from the centre to the circumference, in order to preserve the same area of passage for the current at all distances from the centre of the fan, so that the velocity of the air should continue uniform throughout.

The PRESIDENT said that when the tunnel fan was first set to work, the tips of the blades were curved backwards, but were not found to be so effective as when straight; and it was in consequence of the decided opinions expressed in connection with the Guibal fan, in favour of making the blades radial at the tips, that he came to the conclusion they should be so, at least in the outer portion, whatever might be the form of the inner portion of their length; the blades had accordingly been altered so as to be radial throughout, and he believed the alteration had been for the better. It had to be borne in mind that, under the particular circumstances of the tunnel fan, a special object kept in view in making it in its present form had been to have as much ventilating power as possible when the fan was at rest, by taking advantage of the heated air produced by the passage of locomotives, and the heat from the fan engine, so as to get up a considerable amount of natural ventilation; the fan had therefore been made of as open a construction as possible, with wide spaces between the blades, that it might present the least obstruction to the passage of the air through it when standing; and it was found that the expectations upon this point had been realised in practice. Some modification might doubtless be made with advantage for mine ventilation, where the

fan would always be in motion; but this was not the case in the present instance of the tunnel, as the fan was not at work during the night and part of the day; and it was found that with the wide passages through the fan the natural ventilation alone was sufficient during a considerable portion of each day.

Mr. J. W. Barry suggested that if the width of the tunnel were divided throughout its entire length, by a brattice down the middle, it would only be necessary in this instance to ventilate half the tunnel, as the descending trains made no smoke. He did not know whether such a plan would be applicable in the present case, where the tunnel was a long one, but the question was one that had arisen in his own experience in dealing with a number of short tunnels; and it appeared to him that by dividing them each into two tunnels the interference of opposing currents would be avoided, and the current created in each half by the passage of trains would be always in one direction, whereby the ventilation would be materially assisted. In tunnels of about half a mile length, with only a single line of rails through them, he had found a considerable velocity of current was obtained by the passage of successive trains going always in the same direction, and producing therefore somewhat the effect of a plunger in a pump. In the Liverpool tunnel, though the descending trains did not foul the air, they must produce a cross current interfering with the ventilation, which would be avoided if the tunnel were divided; the expense of the division would not add much he thought to the cost of an ordinary tunnel with double line of way through it, as a tunnel 27 feet wide would well admit of a brattice down the centre.

Mr. C. Cochrane observed that with a partition down the centre of the tunnel, although one side of the tunnel would continue clear on account of the descending trains making no smoke, the ascending trains would have double the effect in fouling the air in the other half of the tunnel; and therefore as much ventilating power would probably still be required for clearing that half as was at present needed for the whole. It was also to be borne in mind that, owing to the tunnel being on an incline, the speed of the ascending trains was lower and would have less effect in aiding the current of ventilation.

The PRESIDENT concurred in the view that the addition of a brattice in the tunnel would increase the degree of fouling occasioned by the passage of the trains on the ascending side. His own experience had been that the effect which the motion of the train produced upon the movement of the air in a tunnel was very slight indeed, and could scarcely be looked upon as of any considerable importance in the ventilation even of a short tunnel.

The following paper was then read:—

ON ASHTON AND STOREY'S STEAM-POWER METER AND CONTINUOUS INDICATOR.

By Mr. JOHN H. STOREY, of Manchester.

In the employment of steam power it is a matter of great importance to be able readily and accurately to ascertain the exact amount of power developed in a given time; but hitherto approximate estimates founded upon the results of isolated tests and experiments, or calculations based upon indicator diagrams taken as averages of the whole work, have furnished the sole means for ascertaining the power developed by steam engines, in all cases where the power has been subject to variation. These indications have been taken at different intervals during a day, or generally during a much longer period; and have simply been registrations of the amount of power developed in the few strokes performed by the engine during the actual time of indication. The variations in the steam pressure, speed, or load upon the engine, which have occurred in the intervals between the indications, have been practically disregarded; and even from the indicator diagrams thus obtained, the power developed during the time of indication can only be ascertained with exactness by a tedious process of measurement and calculation.

The Steam-power Meter and Continuous Indicator forming the subject of the present paper, which is the invention of Mr. Ashton and the writer, possesses the advantages of not only measuring the power developed during a single stroke of the engine with as much exactness as the ordinary indicator, and also of registering this power as exactly as it is measured; but what is of much more consequence, this measurement and registration are effected continuously for the whole number of strokes made by the engine during the entire period of work, whatever variation may occur between the individual strokes. The instrument thus shows at all

times the measure of the power developed by the engine to which it is applied, and registers the aggregate of the power during any required period.

The continuous indicator is shown in Figs. 1 and 2, Plates 18 and 19; it consists of a small cylinder and piston A, like those of an ordinary indicator, but having each end of the cylinder connected by a separate pipe to the corresponding end of the engine cylinder. The piston-rod B is attached at top to an ordinary spiral indicator-spring C, which is compressed or extended when the piston is moved above or below its middle position in the cylinder. The rod also carries a long pinion D, turning loose upon it but held endwise between fixed collars E E; and this pinion gears into a toothed wheel F, which drives a train of wheel-work moving the index on the registering dial of the instrument. Fixed to the lower end of the loose pinion D on the piston-rod is a horizontal plain wheel G, 3 inches diameter, called the integrating wheel, Figs. 3 and 4, having a smooth rim with a rounded edge, which is in contact with the flat face of a vertical circular disc H, $3\frac{3}{4}$ inches diameter, mounted on a short shaft, the disc face being constantly pressed against the rim of the wheel by a light spiral spring J bearing against the end of the shaft; the pressure of this spring is adjusted by a set-screw, and is sufficient to cause any motion of rotation in the vertical disc H to be transmitted to the edge of the horizontal integrating wheel G without slipping. The movement of some reciprocating part of the engine is communicated to the disc shaft, causing the disc to rotate alternately in opposite directions; and the integrating wheel receives from the disc a rotary movement, the amount of which is proportionate to the distance of the point of contact of the wheel with the disc, above or below the centre of the disc. In Figs. 5 and 6, Plate 20, are shown the methods hitherto generally employed for driving the disc. In Fig. 5 a reciprocating iron bar L worked by the engine drives by friction a wheel M having an india-rubber rim, against which the bar is pressed by the lever and pressing pulley N; and the shaft of the india-rubber wheel M carries a pinion gearing into the pinion K upon the disc-shaft, Figs. 1 and 2. In Fig. 6 a cord or strap S from the engine crosshead passes round

a pulley P on the disc-shaft, being carried round guide-pulleys Q Q above and below. Other convenient modes of driving the disc are by means of a reciprocating rack R, Fig. 7, gearing into the pinion K on the disc-shaft; or by a spiral bar T, Fig. 8, carried in bearings at the ends, and rotated by the reciprocating movement of a slide-block U sliding along it.

When there is no pressure on the engine piston, and consequently none on the indicator piston, the height of the integrating wheel G on the piston-rod is so adjusted that its point of contact with the disc H is at the centre of the disc, as shown in Fig. 1, that being the zero point of the instrument; and in this position any rotation of the disc H which is geared with the engine may take place, without transmitting motion to the integrating wheel. But when the steam pressure comes upon the indicator piston, the integrating wheel traverses either upwards or downwards from the centre towards the circumference of the disc, through a distance proportionate to the pressure on the piston, which is measured by the compression or extension of the spiral spring C. Supposing the engine and with it the disc H be moving, the motion will be communicated by the disc to the integrating wheel G, Figs. 3 and 4, and through this to the index of the instrument. The extent of the motion so given to the index during any stroke of the engine is proportionate to the pressure of the steam on the indicator piston during that stroke, because the rate at which the integrating wheel is driven by the disc is directly proportionate to the distance that the integrating wheel is raised or lowered from the centre of the disc, and this distance is the same as the compression or extension of the indicator spring.

When the stroke is finished and the return stroke commences, the disc will rotate in the opposite direction, Fig. 4; and if the steam acting upon the piston were pressing in the same direction as before, the integrating wheel and index would necessarily go backwards. As however the steam acts on the opposite side of the piston when the piston's motion is reversed, the integrating wheel will be moved to the opposite side of the centre of the disc, so that the wheel will still be made to rotate in the same direction as before, Fig. 3; and the extent of forward motion given to the index during the return stroke

of the engine will again be proportionate to the pressure of the steam on the piston during the return stroke, and will be added to the movement of the index during the preceding stroke. By this means therefore the registering index is moved forwards during each stroke of the engine through a space proportionate to the sum of the moments of pressure exerted during that stroke; the total amount of power developed during the stroke is thus indicated, and is added on by the index to that of the preceding stroke. The indication upon the dial is accordingly continuous for the successive strokes of the engine; and the indicator piston being acted upon by the effective steam pressure in the engine cylinder, the power indicated is the net amount of power corresponding to the work actually done.

The following is the mode in which the graduation of the index and the measurement of power by the meter are effected. Assuming the indicator spring to be of such a strength as to yield one inch with a pressure of 25 lbs. per circular inch in the cylinder, the integrating wheel will be in contact with the driving disc at a distance of one inch from its centre when there is that pressure in the engine cylinder; and if the radius of the integrating wheel is one inch, one revolution of the disc will drive it one revolution. Then taking the circumference of the pulley where the motion of the engine is applied to be such that one revolution of the disc is made whilst the engine piston moves through one foot of its stroke, this movement of one revolution of the integrating wheel will represent a motion of one foot by the engine piston under a pressure of 25 lbs. per circular inch, or a moving power of 25 foot-pounds for each circular inch in the area of the piston. In the actual instrument the proportions of the moving parts and the gearing for reducing the motion down to the registering index are so arranged that each unit on the dial represents 1000 foot-pounds per circular inch of the engine piston.

The total work done by an engine in foot-pounds during any period is therefore measured at once by simply multiplying the number indicated on the dial during that period of work by 1000 and by the square of the diameter of the engine cylinder in inches. The

average horse power of the engine during the time is obtained by dividing this total amount of foot-pounds by the number of minutes during which the meter has been in action, and also by 33,000, the number of foot-pounds per minute forming a unit of horse power.* For convenience of reference, where the indicator is intended to be employed constantly for a particular size of engine, a separate index can be provided on the dial for showing at any time the load on the engine in horse power, by simply observing the movement recorded by the index during one minute. For this purpose it is only necessary that the index wheel should be proportioned to the square of the diameter of the engine cylinder, in order that the graduations on the "horse power" dial may represent the product of the whole amount of foot-pounds per circular inch of the engine piston, multiplied by the square of the diameter of the cylinder in inches and divided by 33,000.

By closing the cock connecting one end of the indicator cylinder with the corresponding end of the engine cylinder, and opening a small drip cock to admit air freely to the disconnected end of the indicator cylinder, the indicator is rendered single-acting, and will show the manner of working and the amount of work done by one end of the engine cylinder alone. By opening the closed cock, and closing the open one the action is reversed, and similar information is obtained respecting the other end of the engine cylinder. The connecting pipes from the indicator cylinder to the engine cylinder are made as short and direct as possible; and for convenience of repairs, as well as for cleaning the inside of the indicator cylinder and the piston, the bottom connection is made by a brass plug V, Fig. 2, of the full diameter of the cylinder. This plug is inserted

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*The two calculations may be represented in a concise form by the following expressions for the total work done and the average indicated horse power during any period :—

$$1000\,(N-n)\,d^2 = \text{total work done in ft.-lbs.}$$

$$\frac{1000\,(N-n)\,d^2}{33{,}000\,m} = \frac{(N-n)\,d^2}{33\,m} = \text{average indicated horse power;}$$

where d is the diameter of the engine cylinder in inches, n the reading of the index at the commencement of the period, N the reading at the end of the period, and m the number of minutes elapsed between the times of reading.

through the casing of the instrument into the bottom of the cylinder, and can be readily taken out at any time; and the piston-rod being detached from the spring C at the top, and from the two collars E E upon it, can then be drawn out with the piston through the bottom of the casing, thus affording an easy means of also changing the integrating wheel G if required.

The effect of early closing of the exhaust in producing "cushioning," or compression of the exhaust steam in front of the piston, is shown at the end of each stroke by the integrating wheel turning backwards through a distance proportionate to the loss of power by the cushioning. In the case of a non-condensing engine, with the indicator connected to one end only of the engine cylinder, the integrating wheel would not come back to the centre of the rotating disc during the return stroke of the engine, by a distance proportionate to the back pressure opposing the motion of the engine piston; and the effect would therefore be that during the return stroke the integrating wheel and index would be wound backwards through a distance proportionate to the loss of power by back pressure.

The instrument can be so constructed that ordinary indicator diagrams may be taken by it, for indicating the action of the steam in each end of the engine cylinder separately, or in both ends conjointly. The rotating barrel W, Fig. 1, for taking diagrams on paper, is carried on a bracket, which slides into a groove in the side of the indicator box at X, the driving cord being actuated by some reciprocating part of the engine, while the tracing point is carried by the upper collar E on the piston-rod. After taking a diagram by this means, the barrel on its bracket can be removed from the box and replenished with a blank sheet of paper, and another diagram can then be taken as before.

In cases where engine power is supplied to tenants, this continuous indicator furnishes the only means whereby the power supplied may be accurately measured, on account of the impracticability of obtaining from any isolated strokes of the engine a correct average of the whole. Also in the case of marine

engines in a rough sea, it is the only instrument that can give reliable information respecting the power exerted by the engines, as it is frequently impossible during a whole voyage to obtain consistent diagrams from the ordinary indicator. The instrument is also applicable to the air cylinder of a blowing engine, for the purpose of indicating the weight of blast supplied by the engine in a given time, whatever variation there may be in the pressure of blast or speed of engine during that time. In a slightly modified form it is also useful for determining the power given out by a turbine water-wheel, during any length of time and under all conditions of variable pressure and velocity. Another valuable use of the instrument has been found to be for testing the amount of power required in rolling mills for the manufacture of rolled iron bars and plates, copper and brass tubes and sheets, &c.: no means having hitherto been available for obtaining any reliable information on these points. Two of the first instruments made were applied, one to the engine of an iron-rolling mill in South Wales, and the other to that of a copper and brass tube and sheet manufactory, near Manchester; and during the period of more than twelve months that they have now been in use they have given very valuable information, showing the exceedingly variable nature of the work, and the great difference in the power required for the different classes of work. By recording the aggregate power during any period, the continuous indicator supplies the means for forming a correct judgment as to whether the engine power has been duly maintained during the whole period, and whether at any time there has been a want of due economy in fuel; and the comparative merits of different kinds of fuel or lubricants may thereby be tested definitely.

The following instance of the application of one of these steam power meters to a large pumping engine in the neighbourhood of Manchester may be referred to as an illustration of the important practical utility of the information afforded by the instrument as to the conditions under which an engine is performing its work. The engine in this case is employed in raising water from a river into a reservoir about 16 feet higher, and the piston-rod of the steam cylinder is attached direct to the pump-rod. The pump is a large

ram of about 44 inches diameter with a stroke of 9 feet, and by the action of the steam below the piston together with a vacuum above it the ram is raised, and the water from the river is drawn up by it into the pump-barrel below the ram; a portion of the steam is then allowed to pass round from the under to the upper side of the piston by means of an equilibrium valve; and the piston, piston-rod, pump-rod, and ram descending by their own weight force the water out through the upper portion of the pump-barrel into the reservoir. On attaching the power meter to the engine it was found that 25 double strokes were usually required to move the index of the instrument one unit on the dial, which in this case represented 2000 foot-pounds per circular inch in the area of the engine cylinder. The index was of course observed to move forwards during each upstroke of the engine, thereby showing work done; but during the downstroke it was seen to go backwards through a portion of the space over which it had advanced during the preceding upstroke, thereby showing work undone, in consequence of a portion of the steam that had been employed in the upstroke being uselessly confined under the piston in the downstroke to arrest the descent of the ram. The instrument thus clearly pointed out that the moving parts were too heavy, their excessive weight requiring more steam to raise them than was equivalent to the work done in the water lifted; and the amount of the excess was shown by the backward movement of the index. By comparing the number of revolutions of the integrating wheel during its backward movement with the number of those during the forward movement, the relative loss of effect is obtained; and this was found to be in the proportion of 3 to 10, showing that 3-10ths of the steam power employed was exerted uselessly in first raising an unnecessary weight and afterwards restraining its descent, the remaining 7-10ths alone being usefully expended in raising the water and overcoming the friction of the engine.

As 25 double strokes of the engine were required for a total work of 2000 foot-pounds per circular inch, the work done per stroke was 80 foot-pounds per inch; and the length of stroke being 9 feet, the average effective pressure on the piston was 8·9 lbs. per circular inch. As the effective pressure was only 7-10ths of the total pressure, the

latter amounted to 12·7 lbs. per inch, and the pressure lost was the difference or 3·8 lbs. per inch. The total pressure would be equivalent to the load of water lifted, together with the dead weight of pump-rods &c., *plus* the friction of the engine; while the pressure lost would be equivalent to the dead weight of pump-rods *minus* the friction of the engine. The height of lift of the water being 16 feet, the load of water was 5·4 lbs. per circular inch; and it follows from the amount of the total pressure, that the dead weight of pump-rods &c. amounted to 5·6 lbs. per circular inch, and the friction of the engine to 1·7 lbs. per inch. The steam piston being 44 inches diameter or 1936 circular inches area, the amount of pressure lost, 3·8 lbs. per inch, showed an excess in dead weight of 7357 lbs. or $3\frac{1}{4}$ tons that required counterbalancing.

While the power meter was attached to this engine, numerous indicator diagrams were repeatedly taken from both ends of the cylinder simultaneously, from which the work performed by the engine was computed in the ordinary way; and the results when compared with those shown by the power meter for the same time were found to be closely coincident, sometimes one being slightly in excess, and sometimes the other. Each varying circumstance in the action of the steam in the cylinder was distinctly exhibited by the meter, and the "cushioning" of the steam at the termination of the stroke was shown by a sudden backward rotation of the integrating wheel, which was reversed again at the beginning of the return stroke of the engine. Instead of 25 strokes of the engine being required to move the index of the meter through one unit on the dial, from 28 up to even 34 strokes were sometimes required for registering one unit. The cause of these discrepancies in the readings was found to be the different heights of the water in the river owing to freshets at the different times of observation. So faithful a recorder of the power exerted was the meter found to be, that from its readings the depth of the water in the pump-well could at any time be ascertained.

The extended use of the steam power meter on ocean steamers and other large engines has fully established confidence in the

accuracy of its records, and also in the solidity and durability of its construction. The regularity of its working is illustrated by the following results from the continuous indication of one of the engine cylinders in the Cunard steamship "Siberia" during two voyages from Liverpool to New York and back, the time being nine days in each case; the engine has two 62 inch cylinders with 3 ft. 6 ins. stroke.

		Total Indication of Meter per day.*			Indicated Horse Power.		
		Lowest.	Highest.	Average.	Lowest.	Highest.	Average.
First Voyage..	Out ...	3520	3795	3667	567	612	588
	Home	3378	3751	3595	555	628	601
Second Voyage	Out ...	3548	3722	3678	566	592	585
	Home	3400	3610	3510	500	608	574

* The intervals between the readings of the meter were not exactly a day, but within one hour variation from 24 hours in each case.

In cases where the united action of two steam cylinders is employed to propel the same machinery, if a continuous record of extreme accuracy be required it will of course be necessary to have a meter attached to each cylinder. But the expense of a second meter may be avoided and very valuable results may be obtained, sufficiently accurate in practice for most purposes, by the simple expedient of connecting the cylinder of a single meter to each cylinder of the steam engine by junction pipes and taps, so that communication may be made with either cylinder at pleasure, and the amount of work done by either through any given time can then be ascertained, although but one meter is used. Of the whole work done by both cylinders in combination it is to be considered that a certain definite proportion is done by each, and that this proportion is invariable so long as the degree of expansion and the working condition of each engine remain the same. In order to determine this constant proportion between the two engines, the power of each is measured separately during two successive periods, at some time when the load on the engines is uniform and not subject to any material variation during the trial. The total power of the two

engines can then be ascertained at any other time, by measuring the power of one engine by the meter, and adding to it the corresponding proportionate power of the other.

Mr. Ashton exhibited specimens of the power meter, one of them driven in the ordinary manner hitherto employed, by means of a plain iron bar driving by frictional contact a wheel with an india-rubber rim; and the other meter showed the more recent mode of driving by a rack and pinion.

The President asked what was found to be the durability of the integrating wheel, upon which the accuracy of the indication depended; and what material the wheel was made of.

Mr. Ashton said the rounded rim of the integrating wheel was the part most exposed to wear in the instrument, and he showed one of the first wheels made, which was of ordinary gun-metal and had been in constant use for fifteen months, working most of the time both night and day; it had now become worn flat in the middle of the rounded rim, the amount of wear being somewhat less than 1-300th inch, which on the original radius of $1\frac{1}{2}$ inches was less than 1-450th part of the whole, and the error thereby occasioned in the indication would consequently be less than $\frac{1}{4}$ per cent., requiring 1 horse power to be deducted from every 450 indicated. The wheel could readily be taken out at any time, and replaced in a few minutes, whenever it was considered to be worn down too much for continuing at work. Steel, cast-iron, and wrought-iron had also been tried for the discs working against the integrating wheels; but they were now made, as well as the integrating wheels, of the very hardest bell-metal, considerably harder than the worn specimen exhibited, and so hard that it could only just be worked with the tool. There was no lubrication between the integrating wheel and the disc face, which were

perfectly clean and dry when put to work; and being completely enclosed within the case of the instrument, they were thoroughly protected from risk of any grease or oil getting upon them and interfering with the requisite adhesion between them.

The PRESIDENT enquired what amount of pressure was put upon the disc by the spring at the end of the disc-shaft, for keeping the integrating wheel and the disc always in contact.

Mr. ASHTON said the pressure exerted by the spring was very slight, only just enough to keep the disc in contact with the edge of the integrating wheel, and he did not think it exceeded ¼ lb. The external set-screw afforded the means of adjusting the spring to the degree of pressure that was found sufficient for the purpose.

Mr. J. ROBINSON asked whether any error was occasioned in the indications of the instrument by variation in the elasticity of the main spiral spring at different parts of its range; or whether it was found that the degree of extension or compression under equal additions of force was the same throughout the whole extent of movement. In such springs he thought the resistance to equal additions of force was less at the commencement than in the higher parts of the scale.

Mr. ASHTON replied that in testing the springs within the range at which they worked in the indicator the resistance both to extension and compression was found equal, and was uniformly proportionate to the amount of displacement of the spring. The lengthening or shortening of a spiral spring being due to a torsional rather than an extensional or compressional strain on the material, there was no reason why it should require more force to twist it one way than the other, within moderate limits; and the amount of yielding was accordingly in direct proportion to the total pressure exerted.

Mr. E. A. COWPER observed that the spiral spring in the power meter now described would be as true as an ordinary indicator spring, and he did not think any error would be involved in that portion of the instrument.

Mr. F. J. BRAMWELL thought it would be well if the continuous indicator were in general use for all classes of steam engines, and

especially for marine engines, as it was very important that the actual horse power expended during a voyage should be correctly known. The total consumption of coal could then be divided by the indicated horse power really obtained from the engines during the whole run, instead of by some abnormal horse power given out in a special trial at a measured mile and assumed as an average of the power developed in ordinary working; the true degree of economy with which the engines were working would thus be ascertained. He thought that when the present instrument had become better known it would be very extensively adopted.

Mr. J. B. Fenby suggested that it would be an improvement if it were practicable for the whole amount of the power developed to be shown by the continuous indicator, with a separate registration of the power lost or work undone, which in the present arrangement of the instrument could only be ascertained by constantly watching the movement of the index or of the integrating wheel, and noting by observation the extent of any backward movements. Without such attention, an engine might be considered to be performing no more than the work shown by the indicator, whilst it might really be exerting a greater amount of power, but at the same time also undoing a portion of its own work.

Mr. Ashton said the object of the indicator was to record the absolute work done by the engine, and any power that was exerted without producing a corresponding useful effect did not get recorded by the index. In all non-condensing engines there was of course a certain amount of loss of power by back pressure of the exhaust steam; and in these or any other cases of loss of power the extent of the loss could be detected with the continuous indicator by trying each end of the engine cylinder separately, disconnecting the indicator first from one end and then from the other; the backward movement of the integrating wheel during the return stroke would then be seen, and the amount could be noted for each end of the cylinder. With both ends of the cylinder connected to the indicator, the effect of the back pressure was deducted in the instrument itself from that of the driving pressure, and the movements of the indicator piston corresponded therefore with the effective pressure in the cylinder,

and thus caused the index to show the net amount of the effective work done by the engine.

Mr. G. D. HUGHES considered the indicator was an important and valuable invention, and one which would supply a great desideratum in connection with the working of steam engines, if it answered its purpose as efficiently as appeared to be the case. The only point which appeared to him to allow room for doubt respecting the certainty of its action was the adhesion between the disc-wheel and the rim of the integrating wheel; and if any lubrication ever got on the face of the disc, or if there were any uncertainty in the pressure with which the disc was held against the integrating wheel, it occurred to him that the wheel might slip and fail to indicate the full amount of power. He enquired whether any diagrams had been taken simultaneously by an ordinary indicator, and compared with those taken by means of the barrel attached to the instrument now described; and whether they were found to coincide, after the continuous indicator had been at work for a length of time.

Mr. ASHTON said it was a necessary condition for the correct working of the continuous indicator that the face of the disc-wheel should be kept scrupulously clean, free from oil or anything which might cause the integrating wheel to slip upon it; and with regard to the pressure of the disc against the wheel, no nicety of adjustment was needed, and it was only necessary to tighten up the external set-screw at the end of the disc-shaft, until the spring exerted the slight amount of pressure that was found sufficient to ensure the disc keeping in contact with the integrating wheel, so as to drive it without slipping. In reference to the diagrams taken with this indicator, the first instrument made had recently been tested in the manner suggested, after many months' working, by comparing the diagrams with others taken simultaneously by a Richards indicator; the latter had a spring yielding 1 inch for every 24 lbs. pressure per square inch, while in the continuous indicator the spring had the same extent of motion for every 25 lbs. pressure per circular inch; and when these differences in the graduation were allowed for, the diagrams from the two instruments were found to be perfectly identical.

Mr. E. B. Marten said he had lately applied the continuous indicator to an ordinary forge engine at a rolling mill in the neighbourhood of Stourbridge, where it acted very satisfactorily; and it afforded information respecting the working of the engine which he had not been able previously to obtain with equal accuracy. It had been found by this means that the actual power developed by the engine was less than had been estimated by the ordinary plan of taking indicator diagrams and calculating the power from them. It was indeed very difficult to ascertain the absolute horse power of a rolling-mill engine in any other way than by some plan of continuous indication, on account of the constantly changing load on the engine. In a trial of 30 minutes' duration with the continuous indicator, the mean power actually developed by the engine was found to be 115 horse power, while the indicator diagrams taken at intervals during the same period with an ordinary indicator gave an average of as much as 163 horse power. In a second trial of the same duration the continuous indicator showed 124 horse power actually developed, while the highest indicator diagram gave 325 horse power and the lowest 89 horse power, the mean being therefore 207 horse power, which was again much in excess of the actual power developed. In such cases therefore diagrams taken with an ordinary indicator, which measured only the power developed in a single stroke of the engine, were quite unreliable as an indication of the average power; and he considered the continuous indicator would be found to be exceedingly valuable for all kinds of work where the load on the engine varied at all. There had been no difficulty in attaching the instrument to the engine, and it was worked by a strap from the radius rod, passing round a pulley on the disc-shaft of the indicator, with a weight hung on the other end of the strap to keep it stretched tight and pull it back in the return stroke. This had been found the most convenient method of working in that case, and he was not then aware of the other modes of driving that had been subsequently proposed.

Mr. E. A. Cowper mentioned that an early application of the principle of an integrating wheel and disc for affording continuous indication had been made by Professor Moseley in a steam-power

indicator which had been employed for measuring the power of the Cornish pumping engine at the East London Water Works.

Mr. Ashton said the integrating wheel and disc had long been known; but he believed the integrating wheel had not previously been made to cross the centre of the disc, working alternately above and below the centre, as was the case in the power meter now described, whereby a continuous indication was now obtained from both ends of the engine cylinder, showing the total effective power developed.

Mr. A. Alexander concurred in believing that in the previous use of the integrating wheel and disc, which had been referred to, the wheel did not travel backwards and forwards across the centre of the disc, but continued always on the same side of the centre. An integrating wheel had been originally employed he believed by Morin, in the construction of his registering dynamometer.

Mr. E. A. Cowper asked what was the cost of one of the continuous indicators, as that would be an important consideration in relation to its general adoption.

Mr. Ashton replied that the cost of the instrument was about £20, without the addition of the indicator barrel for taking diagrams, which would be about £3 extra. There were now about thirty of the indicators in operation.

The President observed that questions of priority of invention did not come within the scope of the Institution, and it was always quite possible that other minds might have been on the same track previously; at all events in the present instance it did not appear that the results of former attempts had been to bring forward a practical arrangement in such a shape as should commend itself for general use. This merit however he thought was possessed by the instrument now described; and the only objections raised against it were of a refined and theoretical nature, and in practice did not amount to anything of importance. The wear of the integrating wheel, for instance, was shown to be practically inappreciable; and the same was the case with regard to any slight difference that might perhaps occur in the strength of the indicator spring when considerably compressed or elongated, the diameter of a spiral

spring, and consequently the leverage of the load upon it, being of course increased slightly by compressing the spring, and diminished by elongating it. This continuous indicator appeared to him therefore to be theoretically almost perfect, and in practice quite so; and he considered it a very valuable instrument. He proposed a vote of thanks to Mr. Storey and Mr. Ashton for the paper, which was passed.

The following paper was then read :—

ON THE PRINCIPAL CONSTRUCTIONS OF BREECH-LOADING MECHANISM FOR SMALL ARMS, AND THEIR RELATIVE MECHANICAL ADVANTAGES.

By Mr. WILLIAM P. MARSHALL.

The general adoption of Breech-Loading Small Arms that has now taken place has caused a number of mechanical contrivances to be brought out, of great ingenuity and interest, for overcoming the difficulties met with in obtaining a satisfactory breech-loading action. The objects to be effected are—1st, to open the breech of the gun and close it again rapidly and securely by a simple and convenient movement, without removing the hand far from the trigger, and without shifting the hold of the gun by the other hand; 2nd, to extract the empty cartridge-case of the previous charge by the same movement as that which opens the breech, so as to present the open barrel ready for instant re-loading; and 3rd, to have the whole mechanism of a simple, strong, and durable character, free from risk of derangement either by accident, long wear and tear, rough usage in active service, exposure to wet or sand, or fouling from long continued firing. In the case of military guns the latter requirements are of special importance, as the whole value of a breech-loading gun in increased rapidity of fire would be outweighed by any increased liability to failure in action. When the formidable and conflicting character of these requirements is considered, it will be seen how much mechanical credit is involved in the very complete and successful manner in which they have now been met.

Breech-loading guns were first adopted by the Prussian army, in which the celebrated Needle-gun has now been in use for more than twenty years, and for many years has been the universal arm there used; but the introduction of the principle into other countries is only of recent date, and in this country, although breech-loaders

have for fourteen years been in use to a limited extent for the cavalry carbines, it is only within the last five years that the principle has been adopted for the army generally. In the case of the cavalry carbines, breech-loading was adopted solely for the purpose of overcoming the difficulty of loading whilst on horseback the muzzle-loading rifles then in general use for the army, in which the charge had to be driven home by the ramrod in loading. The breech-loading action then adopted for the purpose was required by the military authorities to fire a paper cartridge, ignited by the ordinary percussion cap, which had to be put on for each charge, involving the consequent loss of time and inconvenience in loading.

A great objection was felt at that time by the military authorities of this country to any considerable increase in the facility for rapidity of fire, on the ground of a supposed risk of ammunition being wasted by too rapid firing before the men came within effective range, leaving them then unduly short of ammunition. The extension of breech-loaders for military purposes was consequently checked in this country for many years, although the principle came into universal use for sporting purposes on account of the great advantages experienced in convenience of loading and rapidity of fire. But the continued experience of the Prussian needle-gun proved conclusively that the objection of risk of wasting ammunition had no real foundation, and that with men properly trained to the use of breech-loaders there was no more risk of ammunition being wasted with them than with any other gun; whilst on the other hand the overpowering command given by the great increase in rapidity of fire made it a case of simple necessity for all other troops to be armed also with breech-loaders, in order to prevent their being placed under a heavy disadvantage. With the use of breech-loaders it has been found that each man is enabled to fire about ten shots whilst advancing from 400 yards to 200 yards range, each shot being fired with definite aim from the knee, and 45 per cent. of the shots hitting a target of 6 feet height and 2 feet width. Troops armed with muzzle-loaders would be at a heavy disadvantage opposed to such a force; and the great power of defence given by breech-loaders against approaching cavalry renders an attack impracticable on open

ground, the infantry being enabled to fire as many as twelve volleys during the time of the cavalry approaching after having come within range.

Several distinct principles of action have been followed in the different constructions of breech-loading mechanism, the main object in each being to provide the means of rapidly opening the breech and loading the gun, and then closing the breech again so as to resist securely the force of the explosion in firing.

The first principle tried was that of the celebrated Prussian Needle-gun, shown in Figs. 1 to 6, Plates 21 and 22, in which the breech is opened by drawing back a bolt B in a line with the barrel, and the front end of the bolt forms a conical cup that closes the breech, when pressed home by turning the handle of the bolt down on one side into an inclined catch. The explosion of the cartridge C is effected by a steel needle N, Fig. 1, which is driven forwards by a spiral spring, and piercing the base of the paper cartridge passes through the powder, and strikes the fulminate inside a cap situated within the cartridge and immediately behind the bullet, as shown in Fig. 3. The base of the bullet is fitted into a sabot made of compressed paper, which is forced into the grooves of the rifle by the discharge, and causes the bullet to rotate with it.

The spiral spring and needle-carrier A are contained in a tube D which slides within another longitudinal tube B; and this outer tube has also an independent longitudinal sliding movement, and forms a long bolt with a knob handle projecting at the side, as in Figs. 1 to 4. The first action in loading the gun is to withdraw the needle from the barrel by means of the thumb-piece E in the rear of the lock, as shown in Fig. 1, pressing at the same time on a spring-catch F, which requires releasing to allow of the withdrawal. The second action is to draw back the bolt B, carrying the needle and spring within it, as in Figs. 1 and 2, thus opening the breech; the bolt handle is first struck upwards into the position shown in Fig. 2, so as to release it from the side catch into which it fits when the breech is closed. The third action is to insert a fresh cartridge into the barrel through the opened breech, as in Fig. 1. The fourth action is to close the

breech again, by pushing the bolt forwards into its first position, as in Fig. 5, turning the handle down sideways to lock the bolt, as in Fig. 4. The fifth action is cocking the gun by pushing in the end thumb-piece E to its original position, as in Fig. 6, in which it is then retained by the spring-catch F; this compresses the spiral spring, as the shoulder on the needle-holder A is held fast by the trigger-catch I, which allows it to pass backwards when the sliding bolt B is withdrawn, as in Fig. 1, but catches and detains the needle-holder when the bolt is pushed forwards again for closing the breech, as in Figs. 5 and 6. The end thumb-piece E, when pushed forwards for cocking the gun, enters a slot in the back end of the sliding bolt, as in Fig. 6, and holds it from turning, thus preventing any possibility of the breech being opened while the gun remains cocked. The sixth action is firing the gun by pulling the trigger T, which releases the needle-holder A and allows it to be driven forwards by the compressed spring, as in Fig. 3.

This Needle-gun was invented in an imperfect form more than forty years since by J. N. Dreyse, a gunmaker of Somerda in Prussia; and after a long series of experiments with the aid of the Prussian government it was brought to its present form, and has been adopted generally for the Prussian army for the last twenty years. At the commencement of that period the arm generally in use in this country and elsewhere was the old smooth-bore musket, until the invention shortly afterwards of the Minié expanding bullet, which allowed of the general use of rifled barrels for muzzle-loaders. In the Prussian needle-gun the means of closing the breech so as to prevent the escape of gas backwards from the barrel at the moment of firing is by a conical cup at the front end of the sliding bolt, which fits over a corresponding conical end of the barrel, as shown at G in Figs. 3 and 5, and is forced into close contact by the slightly inclined face of the catch into which the handle of the bolt is pressed when turned down sideways, as in Fig. 4. In practice however it is found that this joint is not sufficiently tight to prevent the occurrence of a "spitting" or escape of gas into the face of the firer, which becomes inconveniently great after a long continued use of the gun. A difficulty is also experienced from the injury caused

to the needle by its exposure to the flame of the explosion; and each gun is consequently provided with a duplicate needle for the purpose of repairs. The bore of this gun is one of the large class, 0·610 inch diameter, and a bullet of 480 grains weight is fired with a charge of 70 grains of powder.

The Chassepot breech-loader, shown in Figs. 7 to 11, Plates 22 and 23, designed by A. A. Chassepot, head viewer of military arms at Paris, is the improved needle-gun that has been used by the French army for the last five years. The action is the same as that of the Prussian needle-gun, except that one of the movements in loading—namely the separate act of cocking—is dispensed with, the spiral spring being compressed by the act of pushing the bolt B forwards for closing the breech, as in Fig. 7, instead of requiring a separate movement for the purpose; this is effected by doing away with the internal tube sliding inside the bolt of the Prussian needle-gun, and by carrying the needle-rod and spring A inside the bolt itself in the Chassepot; the head H of the needle-rod is caught and held back by the trigger-nose I when the bolt is pushed forwards, and the spring is thereby compressed ready for firing, as in Fig. 7. The closing of the breech for preventing an escape of gas is done by a cylindrical plug P, Fig. 8, formed with a packing ring of india-rubber J, which is pushed into the barrel, as in Figs. 7 and 10, and is compressed and bulged out laterally by the back pressure of the explosion, so as to make a tight fit to the bore of the barrel; the front metallic face of the plug is made with a stem sliding within the hinder portion, in order to allow of sufficient longitudinal movement for compressing the packing ring. It is found however that this elastic packing is liable to injury by use and by exposure to the heat of long continued firing, and that it fails to keep the breech gas-tight; and as there is no shoulder to the joint, any escape of gas blows backwards direct into the firer's face, and this defect has proved a serious objection in long continued action. Both these needle-guns have paper cartridges, which are intended to be entirely expelled at each successive discharge; but a residue is liable to collect in the barrel, which fouls the breech chamber, and after a time renders the loading difficult. The Chassepot is one

of the small-bore class of rifles, and is 0·432 inch bore, firing a bullet of 380 grains weight with a charge of 85 grains of powder.

For the Russian army a modification of the Prussian and the Chassepot bolt actions—the Berdan gun—has been adopted, in which a metallic cartridge is employed; and an extractor for removing the empty metallic cartridge-case after firing is consequently added to the bolt action, consisting of a hook which lays hold of the cartridge base and is withdrawn with the bolt in the act of opening the breech.

The first employment of the breech-loading principle in the British army was fourteen years since, in the carbines for cavalry; and it was adopted with a view to facilitate loading whilst on horseback the guns then in use; these breech-loaders were limited by the military authorities to the use of the paper cartridges ignited by the ordinary separate percussion caps.

In Sporting Guns the breech-loading principle has long been in general use, on account of the advantages obtained by its adoption; and the breech action generally employed is that brought out by Lefaucheux in France nearly twenty years since. This is shown in Figs. 12 to 14, Plate 24, and the principle of action consists in making a hinge joint in the stock at a short distance in front of the breech, on which the barrel turns down at an angle to open the breech for loading; and the barrel is secured by a spring catch when brought back into its original position in the stock. This construction is shown in the drawing as applied to double-barrelled sporting guns and rifles, and with the Westley Richards modification in the construction of the joint, in which the centre of motion for the breech action is formed by a solid hook H upon the underside of the double barrel; the hook enters into an eye B, Fig. 14, in the end of a strap A, which extends forwards from the breech-piece and lies close up against the barrels when firing, Fig. 13, so that the strain of the explosion in firing is supported by the strap in a line but little below the axis of the barrels. On the upper side of the gun a wedge-shaped projection J from the rear of the connecting piece between the barrels enters into a corresponding

socket D in the breech, Fig. 14, so as to aid by supporting the strain above the level of the barrels, which are thus tied to the breech both above and below the line of strain; the whole is secured by a spring catch C, Fig. 13, which prevents any risk of the barrels being displaced in firing. The handle G of this catch moves sideways on the upper face of the breech-action, as shown dotted in the plan, Fig. 14, and is readily moved while the hand is at the trigger-guard; the barrels then drop into the inclined position shown in Fig. 12, with the breech open for loading. The cartridges used have strong card cases with metallic bases, which require extraction after firing; this is effected by a sliding extractor E, Fig. 12, moving longitudinally below the barrels, and having a claw that lays hold of the projecting rim at the base of the cartridge; the extractor is pushed backwards by a tongue I on the hinge-joint in the act of opening the breech, and by this means the cartridge case is at the same time pushed out of the barrel.

In Military Rifles the remarkable superiority shown by the Prussian needle-gun in the continental war of a few years since drew attention forcibly to the inferiority of the muzzle-loading rifles with which the troops of this country were then armed, and proved the necessity for adopting the breech-loading principle; and it was consequently decided to alter the muzzle-loaders generally into breech-loaders. The gun in use at that time was the Enfield rifle, in which the principle of the Minié expanding bullet was adopted, the bullet being put into the barrel cylindrical, but in the act of firing, a conical plug in the rear of the bullet is driven forwards by the explosion and expands the bullet slightly, causing it to enter and lay hold of the rifled grooves of the barrel.

The Snider breech-action was adopted after a competitive trial, as the best mode of altering the existing stock of rifles, so as to form an efficient breech-loader with the least work in alteration; and it has now been five years in use in the British army. In this action, shown in Figs. 15 to 20, Plate 25, the breech is closed by a block B which lifts and turns over laterally for opening the breech, as in Figs. 15 and 18, being hinged upon a longitudinal pin on one side of

the gun; the breech is then open for inserting the cartridge in loading. When closed again, as in Figs. 16 and 19, the block is securely locked in its place by a spring-catch C, which is withdrawn by a lever D pressed by the thumb in the act of lifting the breech-block. The firing of the cartridge is effected by the ordinary hammer H of the previous percussion-lock, propelled by a flat main-spring in the usual manner, and acting upon a striker-pin J which passes obliquely through the breech-block and terminates at the centre of the cartridge base; this pin has a light spiral spring to draw it back after striking. The cartridge is the regular metallic-case Boxer cartridge, containing a small percussion cap inserted in the centre of its base, which is exploded by the external blow of the striking pin. The cap is a tight fit in the hole in the cartridge base, leaving no opening in the rear for escape of gas from the explosion; and as the sides of the cartridge-case are expanded by the explosion and pressed close against the barrel all round, it is found there is no risk of gas blowing backwards, although the breech-block is only an easy fit. For extracting the empty cartridge-case after firing, an arm E is provided, Figs. 17 and 18, which slides upon the hinge-pin of the breech-block, and the block B itself is made to slide longitudinally upon the hinge-pin through a short distance, carrying the extractor arm with it, as shown in Fig. 17; the extremity of this arm lays hold of the cartridge under the base flange, for drawing it out of the barrel. When the breech-block is lifted to open the breech, it is at the same time drawn backwards upon the hinge-pin by hand, as in Fig. 17, and by this means withdraws the cartridge-case partly out of the barrel, so that it can be dropped out or picked out by hand. The Snider gun is of the large-bore class, and is 0·577 inch diameter, having a bullet weighing 480 grains, fired with a charge of 70 grains of powder.

Since the Snider breech-loader was adopted for the army of this country, several other principles of breech-loading action have been adopted by other countries on the continent.

In the Albini-Braendlin breech-action, shown in Figs. 21 to 25, Plate 26, which is used in the Belgian army, the breech is closed by a hinged block B that opens upwards and forwards, turning upon

a transverse pin at the end of the barrel; when closed the block is held down by a spring-catch C, shown dotted in the plan, Fig. 23, which is withdrawn by the lifting handle D of the block in the act of opening the breech. The breech-block contains a striking pin J as in the Snider, which is struck by an ordinary external hammer H; but the blow is conveyed through a sliding pin P, which is hinged upon the hammer, and passing through a guide enters a short distance into a recess in the breech-block before reaching the striking pin, as shown in Fig. 22. This plan prevents any risk of the gun being fired without the breech-block being fully home in its place; and the sliding pin P serves as a steady pin to hold the block at the moment of firing. The breech-block in the act of closing has the effect of forcing the cartridge home into its place in the barrel. The extraction of the empty cartridge-case is effected by an arm E, Fig. 21, hanging freely on the hinge-pin of the breech-block, and laying hold of the base of the cartridge; a projection on the front of the arm is struck by the breech-block in the last portion of its movement in opening, causing the extractor to jerk the cartridge-case clear out of the barrel. The extractor is made double, with an arm on each side of the cartridge, as shown in the transverse section, Fig. 24.

Another breech-action on an entirely different principle is the Remington, used in the Swedish and other armies, and shown in Figs. 26 to 29, Plate 27. The breech is here closed by a block B shaped like a sector of a circle, which turns down backwards to open the barrel, revolving upon a transverse pin; and when closing the barrel it is held up against the breech by a second sector-shaped block H turning on another centre-pin behind the breech-block, the two sectors mutually detaining and slipping past each other alternately, as shown in Figs. 26 and 27. The front sector B, forming the breech-block, has a square notch in it, fitting close to the end of the barrel, Fig. 27; the back sector H carries the hammer, which strikes a firing pin in the breech-block. The front side of the hammer sector is hollowed out to fit the top cylindrical surface of the breech-block, as shown in Fig. 26; and the rear of the breech-block is similarly hollowed out to fit the top of the hammer-

block, as shown in Fig. 27. When the breech-block is open, as in Fig. 26, it holds the hammer back, and prevents it from moving; and when the breech is closed and the hammer is in the act of firing, as in Fig. 27, the breech-block is prevented from moving by the hammer-block bearing against the hollow surface of the rear of the breech-block. The two blocks combine in resisting the backward force of the explosion when the gun is fired. The extractor for removing the empty cartridge-case is a horizontal slide E, Fig. 26, at one side of the barrel, laying hold of the base flange of the cartridge; a projecting nose on the underside of the extractor is caught and drawn backwards a short distance by the breech-block in the act of opening the breech, and the cartridge is thus drawn slightly backwards, and then picked out by hand. A lever L pressed by a spring into a recess in the bottom of the breech-block holds it steady in its position when closed, Fig. 27; and the tail end of the same lever is made to act as a stop to the trigger T, Fig. 26, preventing it from being pulled off until released by the front end of the lever entering the recess in the breech-block, when the breech is fully closed, as in Fig. 27.

Another different principle of breech-action, the Werndl, used in the Austrian army, is shown in Figs. 30 to 36, Plate 28. This gun has a rotating breech-block consisting of a solid longitudinal cylinder B, Figs. 32 and 33, which turns one quarter round upon a centre pin at each end, situated just below the barrel, as shown in Figs. 35 and 36; it closes the breech by fitting close against the end of the barrel, as in Fig. 31. A cylindrical groove is cut out along one side of the block, and when this groove is turned opposite the barrel, the breech is left entirely open, as in Figs. 30 and 35, ready for inserting a fresh cartridge. The breech-block is held at either extreme of its rotation by a spring S bearing against the projecting end of its centre pin P, Fig. 30, which is formed with two inclined flat sides for this purpose, as shown in the end elevation, Fig. 33. A striking pin J is carried obliquely through the breech-block, for conveying the blow to the centre of the cartridge-base from the hammer H, which is on one side, and is similar to the former percussion-lock hammers. The cartridge extractor is

carried on a transverse pin I just below the barrel, and on the other end of the pin is a horizontal arm, shown dotted in Figs. 30 and 31, having at its extremity a lateral projecting stud, which enters a groove G cut round the cylindrical surface of the breech-block, Fig. 32; by the rotation of the block in opening the breech, the end of the groove is brought down upon this stud and depresses the arm sufficiently to withdraw the cartridge partially from the barrel, as in Fig. 30. The breech-block is made with a slightly spiral face at the rear end, as shown in the side elevation, Fig. 32, by which it is driven home against the end of the barrel in closing the breech, as in Fig. 31; and in opening the breech, the stud on the horizontal arm of the extractor, bearing against the rear side of the groove G in the block, which is cut slightly spiral for the purpose, gives the block a slight longitudinal movement backwards from the end of the barrel, as in Fig. 30.

Another principle of breech-action was the vertical sliding block in the Sharps breech-loader, an American invention, in which the breech was closed by a rectangular block, sliding in a vertical slot, and lowered for opening the breech. The breech-block was moved vertically by an external lever, which fitted up to the trigger guard when closed, and was held there by a slight spring-catch. This principle of action has an advantage in the greater power obtained with the external lever for starting the breech-block when jammed with dirt or rust, as compared with the thumb-piece for opening the breech-block in the actions previously described. This breech-action was adapted to the old paper cartridges with separate percussion caps, and the front face of the breech-block was made with a cutting edge to shear the cartridge end; a small recess was formed in the face of the block to contain some of the powder from the cartridge as priming, which was fired by the external percussion cap upon the nipple on the top of the block.

The breech-action shown in Figs. 37 to 40, Plate 29, by Mr. Henry of Edinburgh, is a recent improved construction of the vertical sliding-block action, combined with an extractor for metallic cartridges, and made self-cocking. The breech-block B is raised and lowered by an arm A moved by the curved breech-lever L, which fits

close to the trigger guard when the breech is closed. The hammer H is drawn back and cocked by the same movement that opens the breech, by the breech-lever L bearing against a tumbler D upon the centre pin of the hammer, Fig. 38, and thus carrying the hammer back when the breech is opened, Fig. 37; but it is then prevented from returning by the trigger catch T, and is left at full cock. The blow of the hammer is conveyed to the cartridge by an oblique striker-pin J carried in the breech-block, the hammer H being situated at one side within the breech-body, as shown in Fig. 40. As the position of the hammer cannot be seen outside, an external indicating arm G is fixed upon the centre pin of the hammer, Fig. 40, for showing its position, and this indicator serves also as a handle for cocking the hammer if desired without opening the breech; a locking bolt F is added on the indicating arm, by which the hammer can be secured, so as to be left safely at full cock. The extractor E is a bent lever, the horizontal arm of which is struck by the bottom of the breech-block B when lowered, as in Fig. 37; and the vertical arm catches hold of the base-flange of the cartridge-case and jerks it out of the barrel. A short bevil at the top of this arm of the extractor serves to push back the point of the striking pin J flush with the face of the breech-block when the block is being lowered. In this breech-action the backward force of the explosion is entirely received by the solid frame of the lock, without any strain upon the moving parts or any tendency to alter their position. The main-spring S which propels the hammer is also made to serve at the other end as the trigger spring, so that a single spring only is employed in the lock. The interior of the barrel can be seen through for inspection when the breech-block is lowered, as in Fig. 37, and the barrel can be cleaned from the breech end.

In the recent improved breech-action shown in Figs. 41 to 45, Plate 30, by Mr. Soper of Reading, the breech is closed by a transverse block B, which moves upwards and laterally to open the breech, turning upon a hinge-pin at the side, as in the Snider; but this action is effected by an external lever L at the side of the lock, Figs. 44 and 45, which also cocks the hammer H and moves the extractor E, and is conveniently situated for being reached by the

hand after pulling the trigger, so as to allow of very great rapidity of fire: the highest result yet obtained in rapidity of fire having been with this breech action. The breech-block is raised and lowered by means of a vertical connecting-rod C, Figs. 43 and 44, moved by the side lever L; and a pin at the upper end of this rod, acting in an inclined slot, withdraws or protrudes a locking bolt I contained within the breech-block B, by which the block is secured when closed down. The side lever also draws back the hammer, when raising the breech-block, and leaves the hammer at full cock; and the blow of the hammer is conveyed to the cartridge by a striking-pin J carried in the breech-block, the projecting point of the pin being drawn back after firing by an incline upon the locking bolt I in the breech-block. A small extra trigger F, Figs. 44 and 45, is employed to lock the side lever L, so as to secure the breech from opening whilst at full cock or half cock; the main trigger T when pulled for firing releases this breech trigger F by an arm projecting backwards from it, Fig. 45, leaving the breech then free to be opened, but the breech trigger can also be released separately by hand to allow of opening the breech at any time without firing the gun. The extractor E, Fig. 41, is a horizontal slide, having at the front end a claw that lays hold of the cartridge-base; and at the back end it is moved by a lever G, which receives from the hammer arm a motion that is slow at first for starting the cartridge and afterwards rapid for jerking it clear out of the gun. The force of the explosion in firing is received by the solid frame of the lock without strain on any moving part. When the breech-block is opened, as in Figs. 41 and 43, a clear sight is obtained through the barrel from the breech end, affording facility for inspecting and cleaning it.

The Martini-Henry breech-loading gun, which has been selected for adoption in the British army as the result of a long investigation and practical trial, is a compound of two independent inventions—the Martini breech-action and the Henry rifled-barrel, which were selected as the most satisfactory in the respective branches of the competition.

The Henry barrel, by Mr. Henry of Edinburgh, is a modification of the rifling of the Whitworth hexagonal barrel, and has the same diameter of bore, with nearly the same twist in the rifling; it is cut with seven equal sides, as in Fig. 60, Plate 34, and has a small projecting angular rib in each of the angles of the polygon, the diameter of the bore being the same at the centres of the sides and the summits of the ribs. The bullet employed is a plain cylindrical one, fitting closely at these fourteen points round the circumference; and the effect of the explosion in firing is to "upset" the base of the bullet slightly, and cause it to lay hold of the ribs of the rifling sufficiently to produce the required rotation of the bullet. The amount of twist in the rifling is one turn in 22 inches length, and the diameter of the bore is 0·450 inch, having a bullet weighing 480 grains, fired with a charge of 85 grains of powder.

The Martini breech-action, by Mr. Martini of Switzerland, is a modification of the Peabody breech-loader, which latter has been partially used in the United States' and other armies during the last five years, and is shown in Figs. 46 to 48, Plate 31. The principle of action of the Peabody consists in closing the breech by a longitudinal falling block B, which is hinged on a transverse pin at the back end, and falls at the front end sufficiently to clear the opening of the barrel, as shown in Fig. 46, the upper surface of the block being hollowed out to allow a free entrance for the cartridge into the barrel in loading the gun. The breech-block is lowered and raised by a curved lever L, which forms the trigger guard when closed ready for firing, Fig. 47, and lifts the block by an arm entering a notch on its underside. The hammer H is an external cock at one side, propelled by an ordinary flat main-spring; the blow of the hammer is conveyed to the base of the cartridge by a striking bar J, sliding in a curved groove in the side of the breech-block. The extractor E is a bent lever, which is struck by the breech-block B when lowered, and is made to jerk the empty cartridge-case out. The cocking of the gun has to be effected by a separate movement of drawing the hammer back.

In the Martini breech-action, shown in Figs. 49 to 55, Plates 32 and 33, the falling block B, the lever L, and the extractor E, are

similar to those in the Peabody; but the hammer and striking bar of that gun have been replaced by a direct-acting striker J impelled by a spiral spring, the whole being contained within the falling breech-block B, and the gun is cocked by the act of opening the breech; when cocked it can be securely locked by a sliding bolt F, Fig. 52, which is moved by a projecting stud at the side, Fig. 53, and prevents the trigger T from being pulled.

The mechanical principle of a falling block hinged in a morticed breech is very good; the whole of the reaction from the explosion is received by the cylindrical hinge-socket A, Figs. 54 and 55, within which the tail end of the breech-block B rests, and as this forms the end of a solid wrought-iron box within which the breech-block works, the strain is resisted by the whole strength of the sides of the box. The hinge-pin D securing the breech-block is made an easy fit in the block, and does not receive any portion of the strain from the explosion, the whole being borne by the cylindrical abutment A; this has been shown by substituting a soft lead pin for the ordinary pin at the joint, when it was found that the pin was not marked by the explosion, proving that it did not receive any strain. The breech-block being centred above the level of the axis of the barrel becomes jammed between the end of the barrel and the rear abutment, if forced above its final position, and there is therefore no risk of the breech being blown open by the explosion; and any risk of the breech-block dropping is prevented by the support of the lifting lever L, Fig. 55, which acts as a strut underneath. It is found however that the block remains stationary in firing, even without any support underneath, on account of the friction of the cartridge-base against the end of the breech-block, which is caused by the recoil pressure at the moment of firing. The action of a falling block has been found thoroughly satisfactory; it is very simple and mechanically good, and has the advantage of presenting no projection from the gun when open; and it has stood successfully a practical trial of several years in different parts of the world, where it has been exposed to great extremes of heat and cold, and of wet and dry climates.

There are however some mechanical details that are objectionable in the Martini lock-action; and one of a very serious character consists in the substitution of a spiral main-spring with direct action, in place of the ordinary flat gun-lock spring acting through a variable lever, as in the Enfield and the other military and sporting guns generally. Although as regards the springs themselves, there may not be any material difference between the two kinds of spring, either in strength, rate of deflection, or durability: yet in their suitability for application to the present purpose the difference is remarkably great. The work to be done is to strike a blow upon the detonating cap in the base of the cartridge, which will indent it sufficiently to explode the fulminate within it; but the spiral spring adopted in this lock, being confined within the limits of the breech-block, is necessarily very short, and the length of its stroke is consequently less than half an inch, being only 0·42 inch; and as the velocity of the striker is only the same as that of the spring, the pressure of the latter has to be increased sufficiently to produce at the moment of striking the blow the velocity that is necessary for the required effect. This has been found in practice to require an average pressure of 28 lbs. throughout the stroke of 0·42 inch, necessitating a spring that has a pressure of 40 lbs. at the beginning and 16 lbs. at the end of the stroke. This amount of pressure, though not material as regards simply the percussive action of the spring, involves a serious practical objection, from the whole pressure of the compressed spring having to be supported upon the sear nose or catch of the trigger action when the gun is at full cock, and from the trigger having to be pulled off under this heavy pressure in the act of firing the gun. The leverage of the spring over the sear nose being nearly double, as seen in Fig. 54, increases the pressure upon it from 40 lbs. to as much as 75 lbs.; and this result is unavoidable, on account of the limited space available above the level of the trigger, and also on account of the action of the spring upon the striker being simple and direct, instead of a multiplied and indirect action. This pressure of 75 lbs. is greatly in excess of that in ordinary gun-locks, and makes the pull of the trigger too stiff to be admissible; the pull is limited to 8 lbs. as the extreme, on account of a heavier pull being objectionable

by disturbing the accuracy of aim, and from 3 lbs. to 5 lbs. is the pull preferred for match-shooting. This point has been felt to be a serious mechanical difficulty in the Martini lock, and a lighter spring was at first tried, but was found liable to miss fire; then an inclined bearing face for the sear nose was tried, to ease the pull-off, but this was found dangerous from the risk of the trigger going off and firing the gun, if jarred by a sharp blow of the stock upon the ground.

The difficulty has now been met by the Superintendent of the Government Small Arms Factory at Enfield, Colonel Dixon, by an exceedingly ingenious contrivance consisting of a double catch for holding the spring, one catch with a square nose for holding it securely whilst the gun is on full cock, and the other with an inclined nose, to which the pressure is partially transferred in the act of firing. The action of this is shown separately in the full-size diagrams Figs. 56 to 59, Plate 34, and consists of two separate catches R and S working independently upon the same centre; the upper one R (called the tumbler rest) has a bearing edge square to the radius, so as to hold the spring securely, as in Figs. 57 and 58, without any tendency to shift under a jar. The lower catch S (which is the end of the trigger T) has an inclined bearing edge, but hangs loosely at first on the centre pin without sustaining any pressure, as its centre is made with an inclined slot-hole; when however the trigger is pulled (in the direction of the arrow), the force of the pull is first expended in sliding the trigger obliquely up the inclined slot of its centre bearing, causing a vertical pressure at its upper end, whereby part of the pressure is transferred from the square nose of the tumbler rest R to the inclined nose S of the trigger. As the pull upon the trigger continues, a greater portion of the total pressure is transferred from the square nose to the inclined nose; until at last the resistance to the trigger is overcome, and the two catches are pulled off together, as in Fig. 59, and the gun is fired. The tumbler rest R is made forked, as shown in the elevation Fig. 56, and the tumbler C bears upon it on each side of the trigger T, the nose of which moves freely within the fork of the tumbler rest, but carries the rest away with it, as in Fig. 59, when the trigger is pulled off. In the diagrams

Figs. 58 and 59 the tumbler rest R is shown beyond the trigger nose S, instead of in the same line with it, for the purpose of illustrating the action more clearly; and in all these Figs. the projecting catch for the sear spring is omitted and the length of the slot-hole in the trigger centre is exaggerated for the sake of clearness; the complete tumbler rest is shown at R in Fig. 54. This highly ingenious contrivance is found to answer the purpose when very carefully made, and whilst in good order and well lubricated; but it introduces into the lock a piece of delicate fitting of an exceptional character, as it requires a nice adjustment of the position of the slotted centre-hole, the length of the trigger to the nose, and the position of the tumbler rest and its bearing, in order that during the pull-off all may work harmoniously together.

The mechanical question to be considered is whether this objectionable complication is unavoidable; or whether by the use of a different kind of spring it can be obviated, without sacrificing any of the good points in the breech-action. This appears to have been satisfactorily accomplished in the lock shown in Figs. 63 to 69, Plates 35 and 36, by Mr. Westley Richards of Birmingham, in which exactly the same breech-action is obtained with an ordinary flat gun-lock spring and hammer, so arranged that the trigger action and the pressure upon the trigger nose correspond with those in the ordinary gun-lock action, which has been proved by general practice to be satisfactory and durable, and to retain a uniform steady pull-off, not subject to wear or alteration. The breech-block B is the same as in the Peabody and the Martini guns, but is raised and lowered by a lever L acting at the front end, and supporting the block as a strut at the point furthest from its centre of motion. The breech lever fits close up to the trigger-guard when the breech is closed, as shown in Fig. 64, and is held by the pressure of a spring at each extremity of its motion. The hammer H works in a hollow in the underside of the breech-block, striking the cartridge through a small hole in the centre of the breech-block face, Fig. 68. The hammer is cocked by the action of the lever L in opening the breech, the arm of the lever carrying the

hammer back, compressing the main spring S, and leaving the hammer caught upon the sear or catch C, which is released by an ordinary trigger T. The hammer can be securely locked at full cock by an external lever F, shown dotted in Figs. 66 and 67, which has considerable leverage for overcoming any friction. The cartridge extractor E is an arm acted on by a shoulder upon the breech lever L, as shown in Fig. 69, which has great power to start the extractor in any case of a defective cartridge having become jammed in the barrel; a spring G acting on the tail end of the extractor, after the first movement of starting the empty cartridge-case by the lever, jerks it out clear of the gun by a rapid motion of the extractor.

In this lock the spring pressure averages 36 lbs. throughout the stroke, and ranges from 44 to 28 lbs., being rather greater than that of the Martini spiral spring, which averages 28 lbs., ranging from 40 lbs. to 16 lbs.; but the leverage at which the flat spring acts is considerably less than that of the sear nose, instead of being much greater as in the Martini lock, and the pressure on the sear nose is consequently only about 12 lbs. at full cock, instead of the 75 lbs. in that lock. An ordinary square-nosed sear is consequently used, and an easy trigger-pull is obtained with a secure hold in the catch; and the pull is found not to alter materially from the effect of rust or want of lubrication. The propelling pressure of the spring measured at the striking point of the hammer is only an average of about 8 lbs. throughout the stroke, instead of the 28 lbs. in the Martini lock; but the length of stroke being as much as $1\frac{3}{8}$ inch at the striking point, about the same velocity is obtained in each case at the moment of striking.

The ordinary gun-lock swivel-action is employed for regulating the propelling effect of the spring upon the hammer, by means of an oblique connecting-link, which by its change of inclination during the stroke, as shown in the full-size diagram, Fig. 62, Plate 34, reduces the effective leverage of the spring as its compression increases, when putting it to full cock. This is seen by the enlarged diagram, Fig. 61, in which the upper dotted lines show the position of the hammer tail and the swivel before cocking, and the bottom full lines

show the diminished leverage of the spring when at full cock. By this means the varying pressure of the spring during the stroke of the hammer is so far modified, that although the spring presses with considerably greater force at the beginning than at the end of the stroke, the propelling force on the hammer is considerably less at the beginning than at the end; and consequently, as it is the force at the beginning or at full cock that has to be held by the sear or catch of the trigger action, the pressure on the catch at full cock is considerably less than the average pressure throughout the stroke, and is reduced to only 12 lbs., instead of the 75 lbs. in the Martini lock. In the arrangement adopted in the latter however, the pressure to be supported upon the catch being directly proportionate to the compression of the spring, is consequently considerably greater than the average pressure throughout the stroke.

It thus appears that in the Martini lock, by the introduction of a spiral spring instead of the ordinary flat gun-lock spring, a serious mechanical difficulty is caused, which is only overcome by the addition of a piece of mechanism of an exceptionally delicate character, requiring an unusual nicety of adjustment to be constantly maintained in order to ensure its continued efficiency of action. But it also appears that the whole of this difficulty and complication is unnecessary, and can be avoided by simply adhering to the ordinary flat gun-lock spring and action and trigger; and that this can be done without interfering with any of the advantages of the falling-block breech-action. On the contrary, in the arrangement of the same breech-action shown in Figs. 63 to 69, Plates 35 and 36, the change is attended with some further advantages of value. The lifting lever acting upon the free extremity of the breech-block is a better arrangement than lifting the block near its centre of motion, as in the Martini lock: as the effect of any wear of the bearing surfaces will be considerably less in affecting the accurate lifting of the block, and the pressure upon the wearing surfaces being less, their wear will be proportionately less. Also the position of the lever, in front of the trigger-guard and fitting close up to it when the breech is closed, is more convenient for the hand, and requires less change from the position of firing, than in the case of the Martini

lock, where the lever is situated behind the trigger guard. This difference has now been made greater by the circumstance that the position of the lever in the latter, just behind the trigger-guard, has been found to interfere with the proper grasp of the stock in bayonet exercise, and the lever is consequently to be extended still further back to remove this objection, as shown by dotted lines in Fig. 50. Another point of detail to be noticed is the mode of fixing the stock into the breech-body, which in the Martini gun is done by making a shallow socket in the rear, Fig. 50, into which the butt of the stock is fixed by a long steel screw passed through a longitudinal hole in the stock: instead of the ordinary plan of having two long straps upon the rear, as shown in Fig. 63, with a transverse screw through the stock. In the trials that have been made some cases have occurred of the stock becoming loose in the socket, from the wood shrinking in hot climates or from imperfect fitting; and in the event of the long screw becoming bent by a blow, the stock has to be sawn off for getting it out; and it appears a question for consideration whether that plan of fixing is so good as the ordinary long straps.

The conclusion arrived at therefore is, that—although in the Martini-Henry rifle, which has been selected as the national weapon, the general principle of closing the breech by a falling block enclosed in a morticed breech, and also the small bore of the barrel with the rapid spiral in the rifling, are thoroughly satisfactory and well suited for general adoption for the army,—yet the details of the lock-action in this gun involve serious mechanical defects, which however can be readily corrected by employing the ordinary principle of construction of gun-lock action, confirmed by long experience; and this correction can be effected without any detriment to the principle of closing the breech, while some decided advantages can be gained as regards other points.

A collection of specimens of the various breech-loading rifles described in the paper was exhibited, and the action of the breech-closing mechanism was shown.

Mr. W. Soper said that, having studied the subject of breech-loading rifles for many years, he had come to the conclusion that one of the most essential conditions of a good breech-loader was that the person firing it should under all circumstances be perfectly safe, and secured from any danger or inconvenience by escape of gas backwards from the breech at the moment of firing. After trying various plans of closing the breech, he had found by experience there was no better mode of preventing backward escape of gas in firing than by the employment of a transverse breech-block, swinging at right angles to the barrel, and hinged upon a longitudinal pin at the side of the gun. In the Prussian and Chassepot needle-guns there was frequently a great escape of gas, when the joint at the breech had become worn by use; and the firer was thereby injured in some cases, and in others was prevented from making effective work with the rifle. In the Martini gun, although the breech-block was securely held up from below, so that there was no danger of its being blown down in the act of firing, yet as it was a longitudinal block working within a longitudinal slot in the breech-shoe there must necessarily be a certain amount of clearance or "freeing" left on each side of the block to allow of its working freely within the slot. When the gun was held in position for firing, these two longitudinal lines of "freeing" were immediately in the line of the marksman's eye; and if there were any unsoundness in the rear of the cartridge, preventing it from forming a gas-tight stopper in the breech of the gun, he considered there would be risk of gas blowing backwards along the longitudinal lines of joint, and injuring the firer; and notwithstanding the number of trials that had been made with this gun, he thought no one would like to fire it with a defective cartridge, having his eye directly over the lines where an escape of gas might take place. These considerations had led him to employ the transverse breech-block working at right angles to the barrel, so that when the breech was closed the lines of "freeing" were also at right angles to the barrel; the effect of the reaction in firing

was then to press the breech-block tight against the abutment behind it, and so form a gas-tight joint at the back of the block, while in the event of using a defective cartridge, or even in firing a charge of loose powder, any discharge of gas that took place was at the joint in front of the breech-block; and by now making the block with a slight projecting lip in front, covering the joint and inclined forwards at an angle of 45 degrees, the issuing column of gas was thrown forwards at that inclination, and blew out quite clear of the firer's face. In consequence of this arrangement, cartridges purposely cut open in three places at the base had been fired from the gun, as well as charges of loose powder, without any inconvenience being occasioned to the firer. The primary condition of safety to the firer having thus been secured by the use of the transverse breech-block, which had also proved so satisfactory in the Snider gun, he had adhered to the principle of the Enfield lock-action as regarded the employment of the ordinary flat main-spring and swivel action for propelling the hammer. The question of rapidity of firing he looked upon as a secondary consideration in comparison with the safety of the firer; but by means of an extractor giving great certainty and promptness of action in removing the empty cartridge, he had succeeded in attaining a greater rapidity of fire than he believed had been reached by any other gun, as many as 60 shots in a minute having been fired from a rest. When taking aim, 30 shots in a minute had been fired from the shoulder, of which 29 struck the target of 6 feet height and 4 feet width at 200 yards range; and scores of 70 to 78 per minute had repeatedly been made with this gun in public trials.

Mr. R. Bird, in exhibiting a specimen of the Henry self-cocking breech-loading rifle, referred to the advantage of a short movement of the hand in opening the breech, and pointed out the short and convenient movement of the breech-lever for opening or closing the breech and cocking the gun. There was only one spring in the lock action, and that was an ordinary flat main-spring; the extractor was simple and strong, and worked efficiently without any spring. In closing the breech, the bevil at the upper edge of the breech-block forced the cartridge home, even though it might have been left

projecting as much as 1-16th or 1-8th inch from the chamber of the barrel, as might occur in rapid loading; whereas in most of the other guns it was necessary that the cartridge should be pushed quite home by the hand, otherwise the breech could not be closed. Another advantage in the Henry gun was that a direct sight was obtained through the barrel when the breech was opened, and consequently the barrel could be cleaned out from the breech towards the muzzle; this he considered a great advantage over those rifles which required to be cleaned from muzzle to rear, as by the latter method the flakes of fouling from the barrel were forced towards the breech action and might get in it and clog it; whereas in cleaning from the rear, the cartridge chamber was first thoroughly cleaned, and the fouling fell out at the muzzle of the barrel. By means of the indicating arm at the side, the gun could either be bolted at full cock, or could be let down to half cock whilst loaded, and was perfectly secure in that position; the indicator could also be used to cock or half-cock the rifle without opening the breech, and in these respects it supplied the place of the outside hammer in ordinary rifles, whilst at the same time it served as an efficient indicator to show whether the rifle was at half or full cock, which was easily seen both in the act of loading and firing. With regard to safety, the rifle had on many occasions been fired with purposely damaged cartridges and with considerably increased charges, without sustaining any injury. As to rapidity of fire, the first and second prizes in the public trial at Wimbledon last year had been won with the Henry gun, 52 shots having been fired in two minutes, all of which hit the target at 200 yards.

Mr. W. Soper remarked that his rifle also cleaned from the rear, and gave a clear sight through the barrel.

Mr. T. Greenwood said that his own opinion entirely coincided with that expressed in the paper as to the mechanical questions involved in the various breech-loaders which had been described, and he fully concurred in the criticisms made upon the Martini breech mechanism.

The President observed that the subject of breech-loading mechanism for small arms was one that was exciting much attention

at the present time, on account of its great interest from a national point of view; valuable material for the consideration of the subject had been furnished at the present meeting, and he thought there would be an advantage in adjourning the discussion.

He therefore proposed the adjournment of the discussion; and also moved a vote of thanks, which was passed, to those gentlemen who had so kindly lent for the occasion of the meeting the numerous specimens of rifles now exhibited.

The Meeting then terminated.

Fig. 1. *Blast Furnace 67 feet high at Askam.*

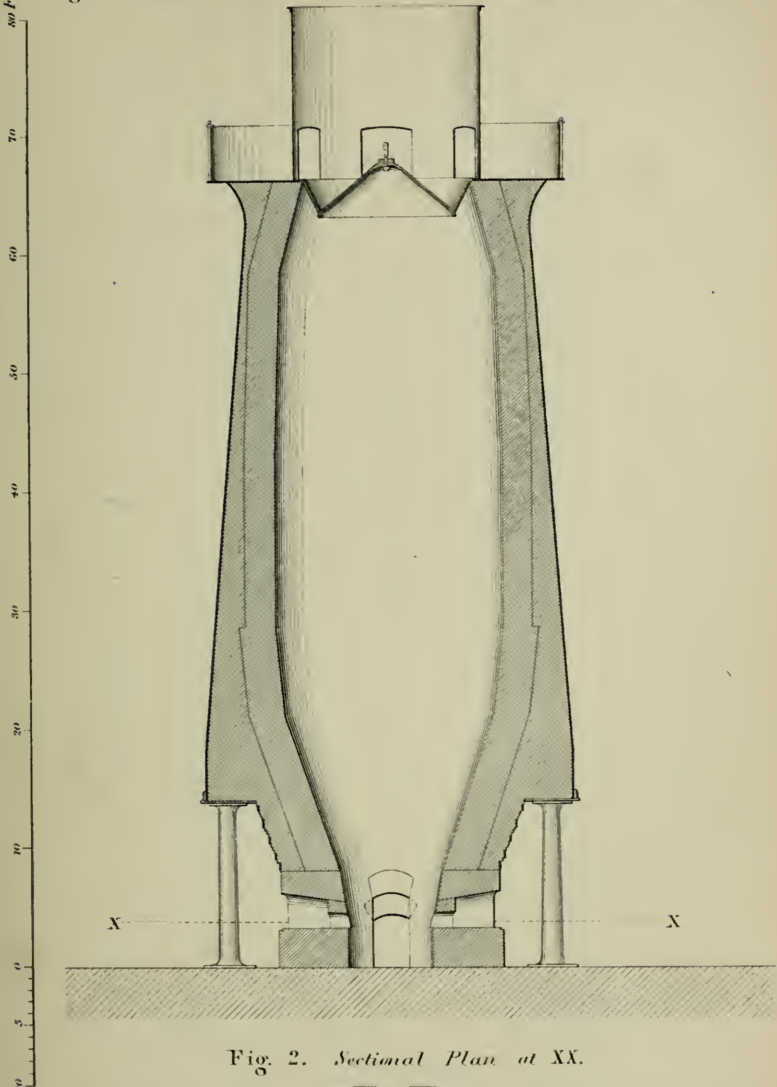
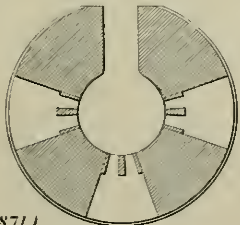


Fig. 2. *Sectional Plan at XX.*



Scale 1/200th

(Proceedings Inst. M. E. 1871.)

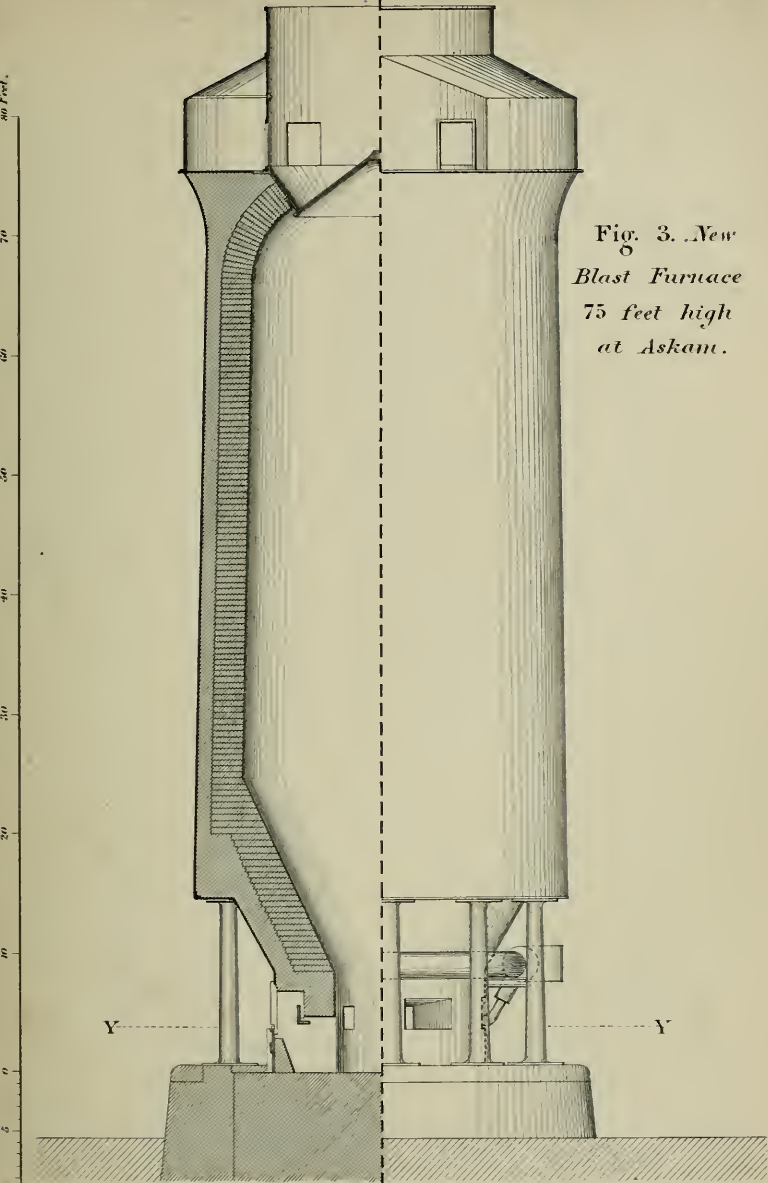


Fig. 3. *New Blast Furnace 75 feet high at Askam.*

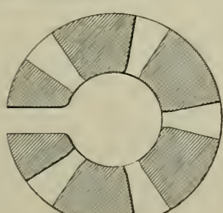


Fig. 4.
Sectional Plan at YY.

Modes of Taking Off Waste Gas from Hæmatite Furnaces.

Fig. 5. *Closed Top of Askam Furnaces.*

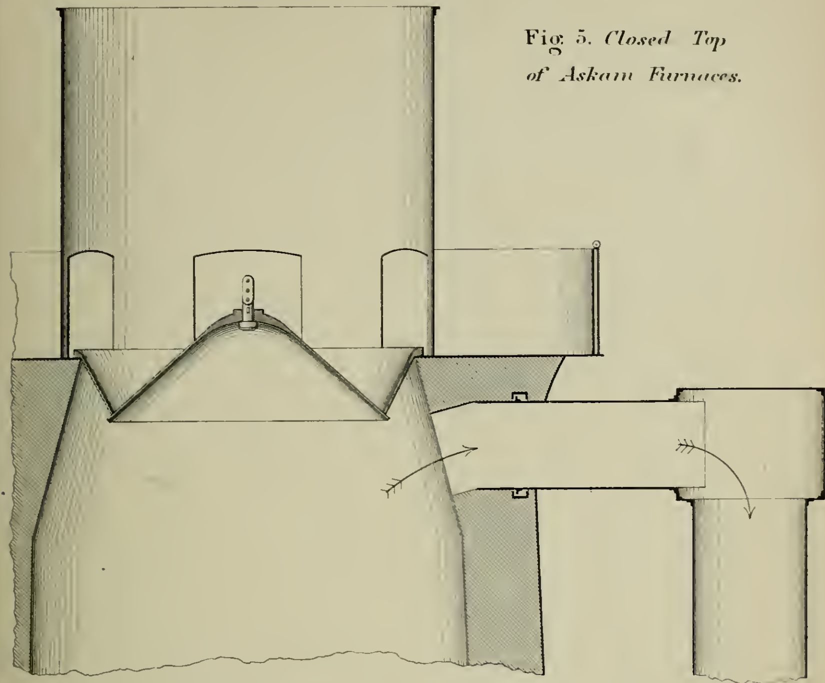
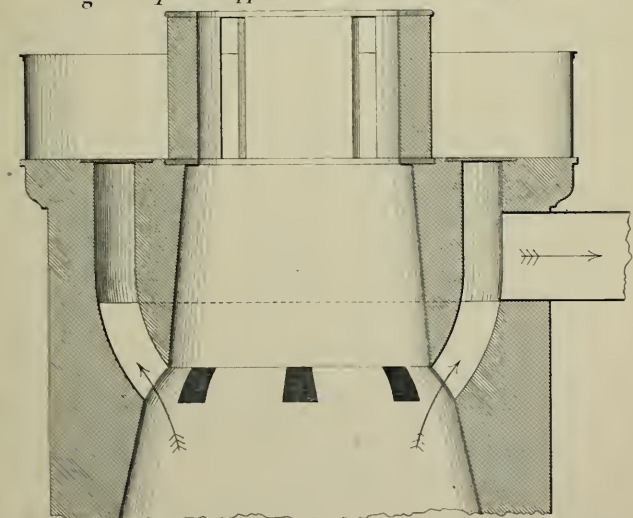


Fig. 6. *Open-topped Hæmatite Furnace.*



(Proceedings Inst. M. E. 1871.)

Scale 1/100th.

10 5 0 10 20 Feet.

Fig. 7. *Semi-closed Top of Barrow Hæmatite Furnaces.*

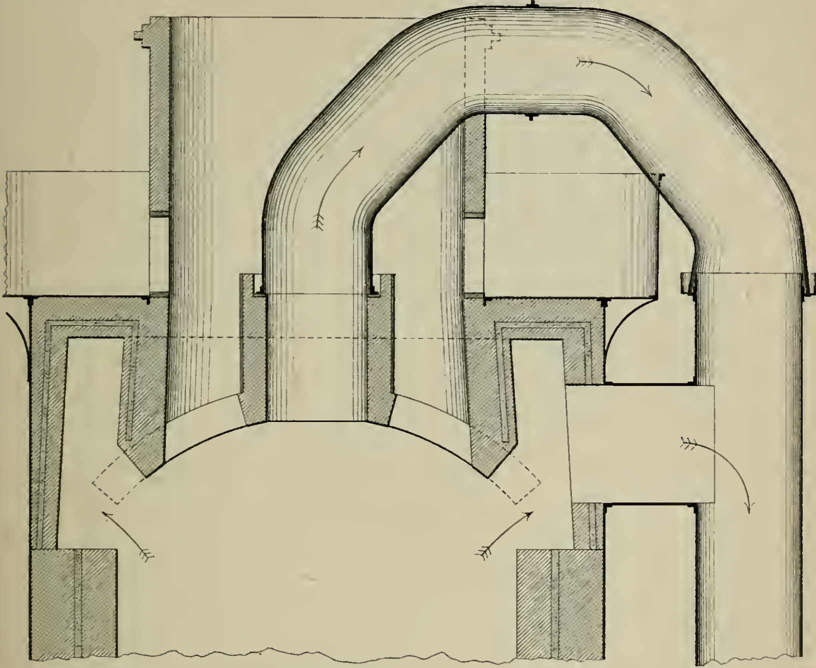
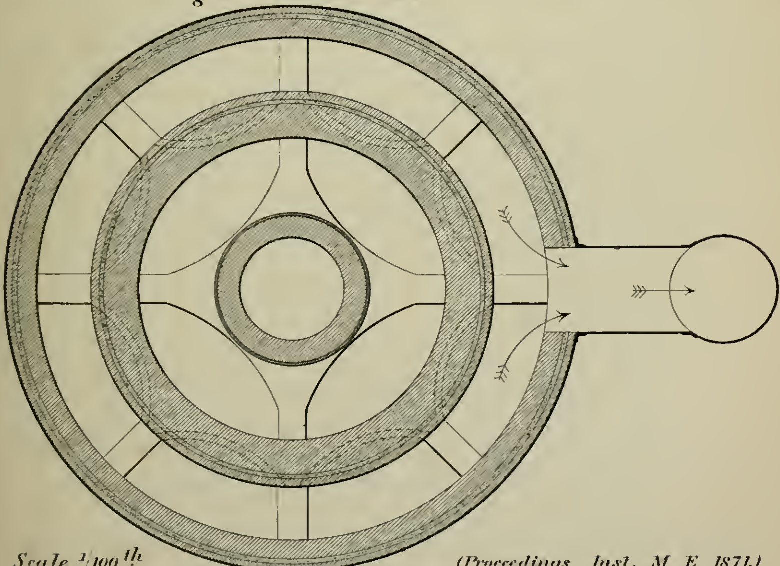


Fig. 8. *Sectional Plan.*



Scale 1/100th

(Proceedings Inst. M. E. 1871.)

10 5 0 10 20 *Feet.*

MANUFACTURE OF HÆMATITE IRON.

Spiral - Tube Water - Tuyere and Tuyere - Breast.

Fig. 9. *Back Elevation.*

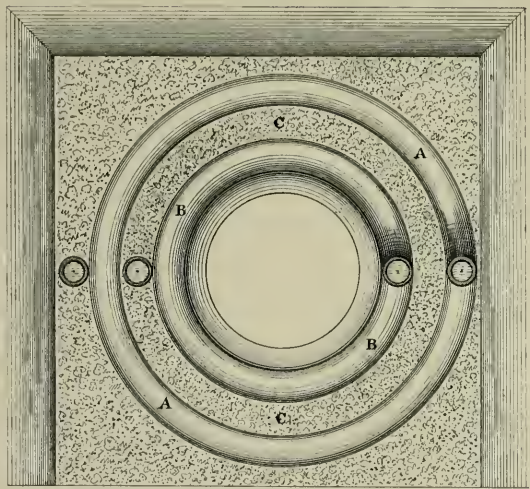
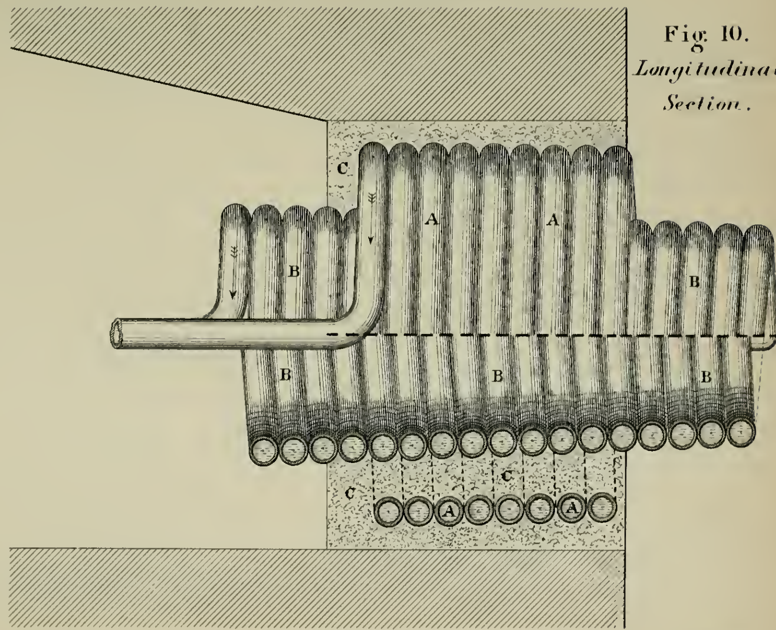


Fig. 10. *Longitudinal Section.*



Scale 1/8th 0 5 10 15 20 *Inches.*

(Proceedings Inst. M. E. 1871.)

[illegible]

Breckon and Dixon's Coke Oven.

Fig. 1. *Section at* XX.

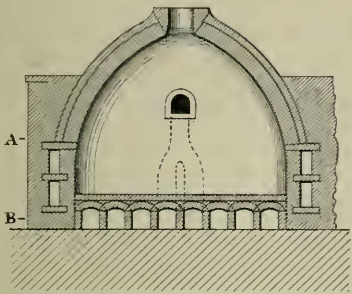


Fig. 2. *Section at* YY.

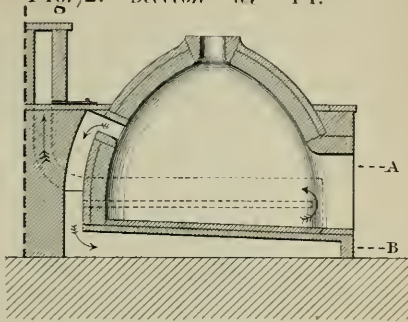
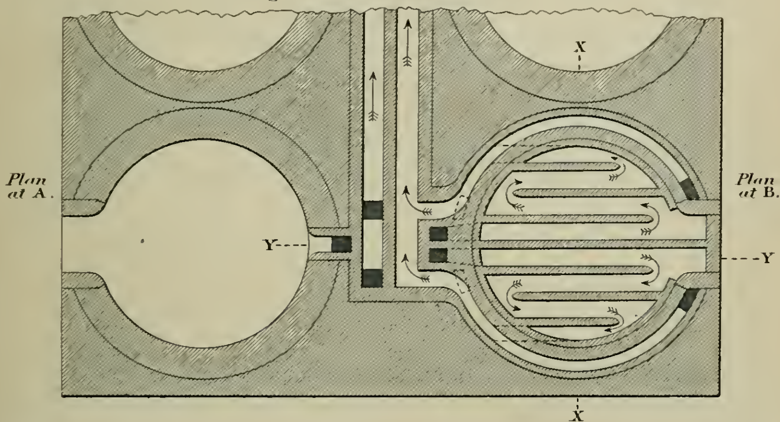
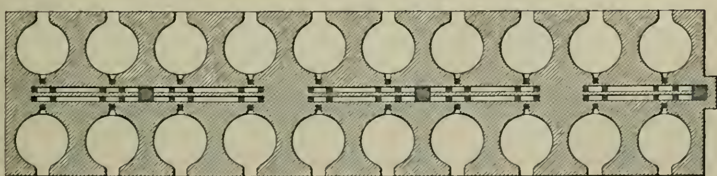


Fig. 3. *Sectional Plan.*



Scale 1/120th 10 5 0 10 20 *Feet.*

Fig. 4. *Plan of Block of 20 Ovens. Scale 1/480th.*



Appolt's Coke Oven.

Fig. 5. *Section at XX.* Fig. 6. *Section at YY.*

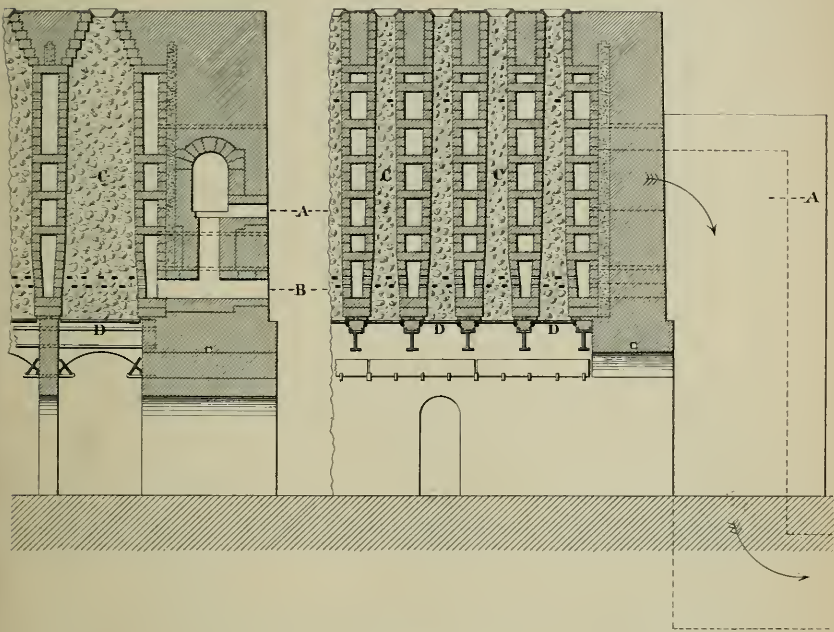
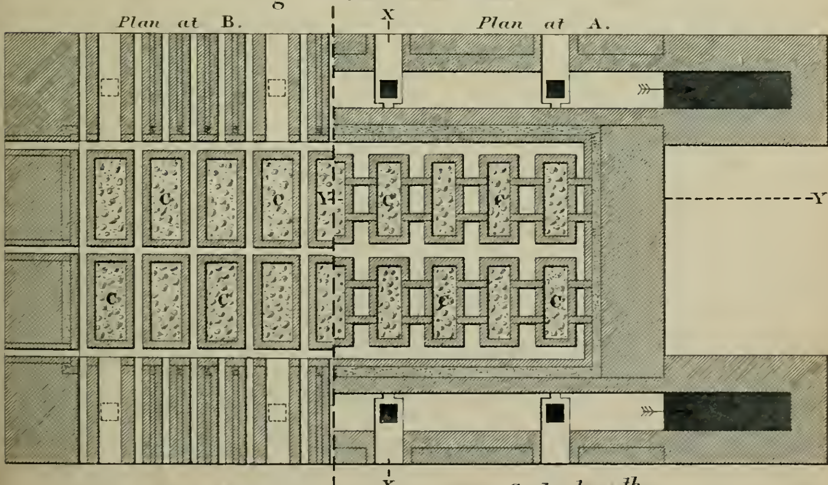


Fig. 7. *Sectional Plan.*



(Proceedings Inst. M. E. 1871.)

Scale 1/120th

10 5 0 10 20 Feet.

Pernolet Coke Oven.

Fig. 8. *Section at* XX.

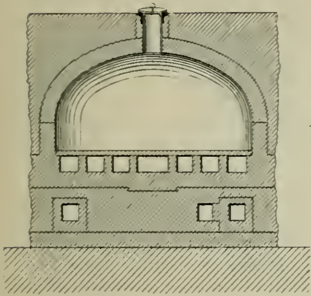


Fig. 9. *Section at* YY.

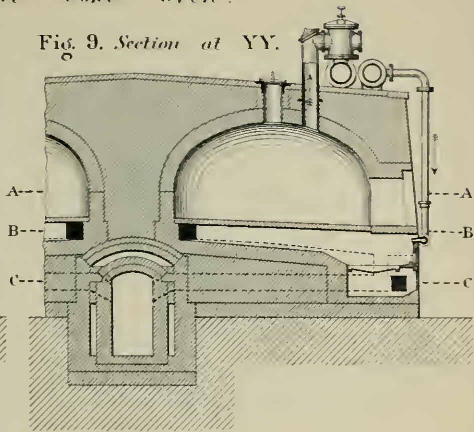
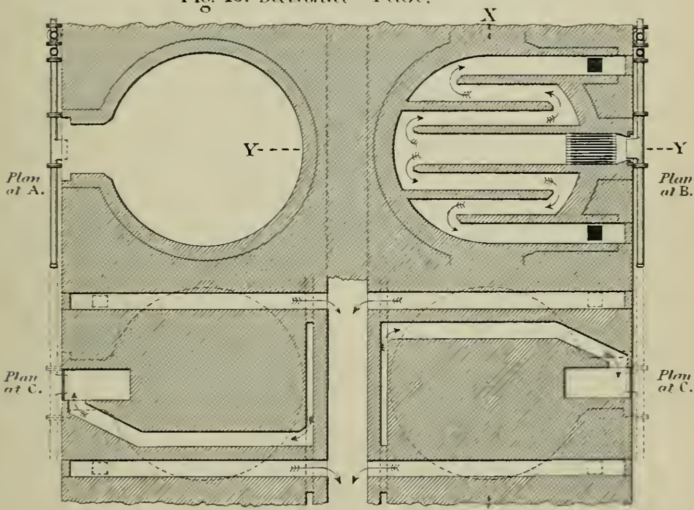
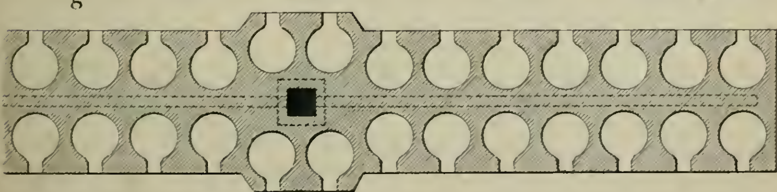


Fig. 10. *Sectional Plan.*



Scale 1/120th 10 5 0 10 20 *Feet.*

Fig. 11. *Plan of Block of 32 Ovens.* *Scale* 1/480th.



Calcining Kiln.

Fig. 12. *Vertical Section.*

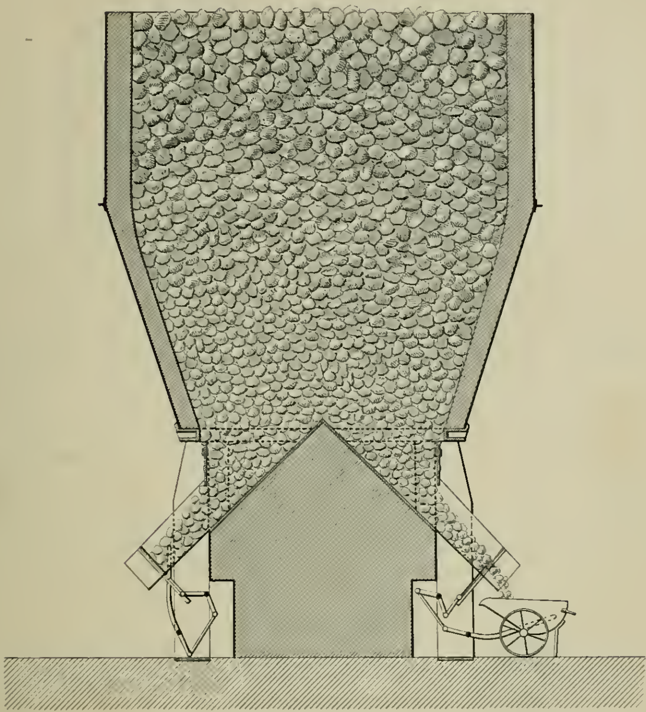


Fig. 13. *Sectional Plan at top.*

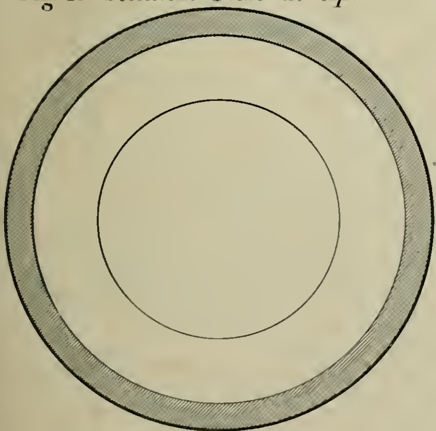
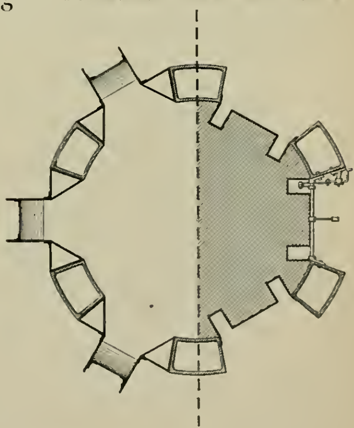


Fig. 14. *Sectional Plan at bottom.*

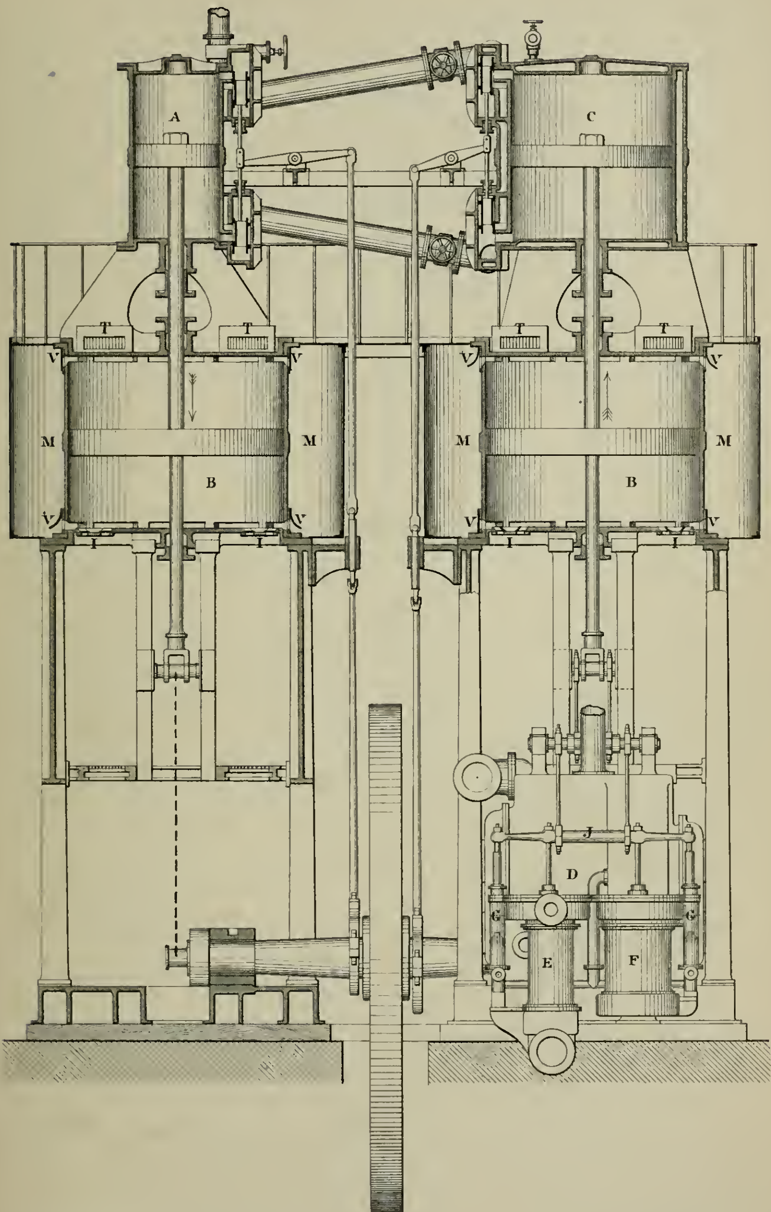


(Proceedings Inst. M. E. 1871.)

Scale 1/120 th.

COMPOUND-CYLINDER BLOWING ENGINES. *Plate 46.*

Fig. 1. *Vertical Section.*

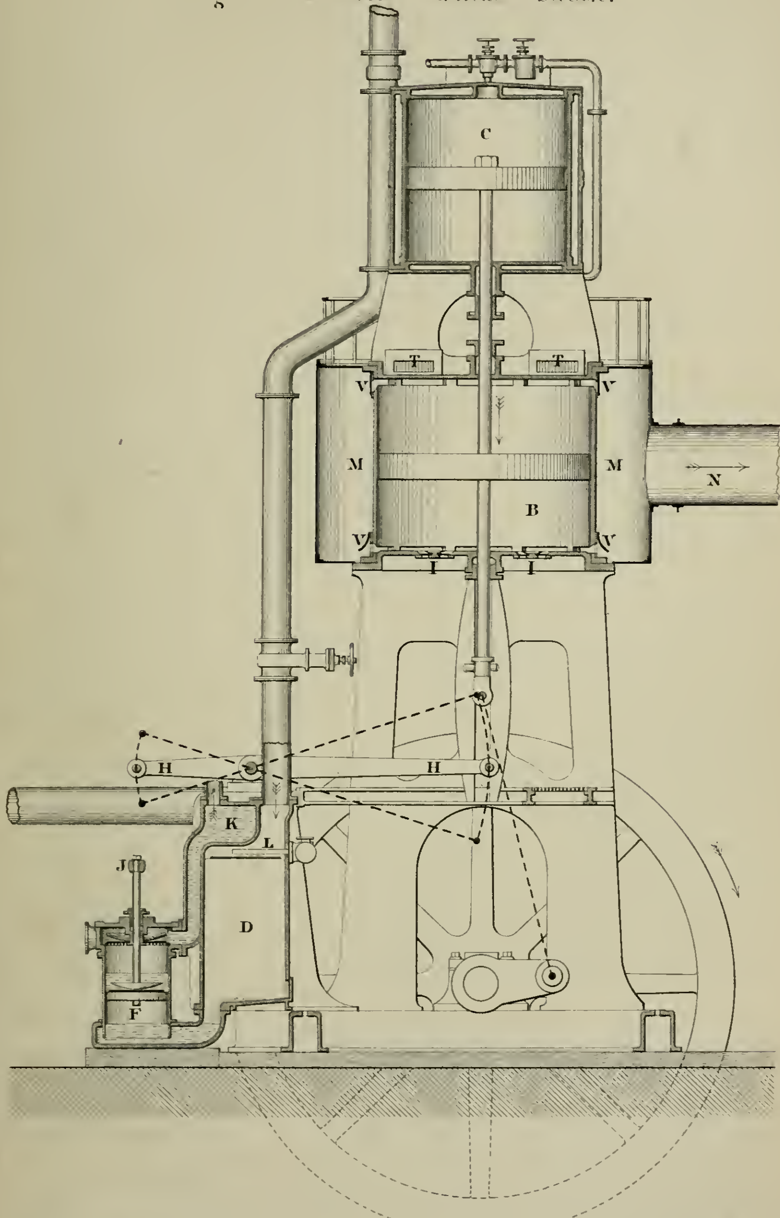


(Proceedings Inst. M. E. 1871.)

Scale 1/70 th

0 5 10 15 20 *Feet.*

Fig. 2. *Transverse Vertical Section.*



Scale 1/70 th

0 5 10 15 20 *Feet.*

Fig. 3. *Plan.*

Scale 1/70th.

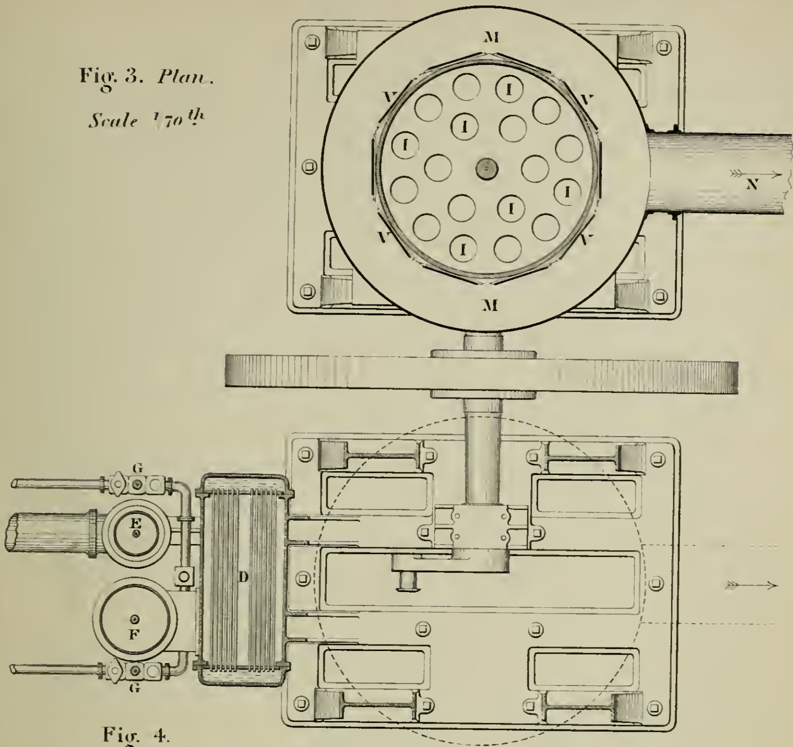


Fig. 4.

Section of Condenser.

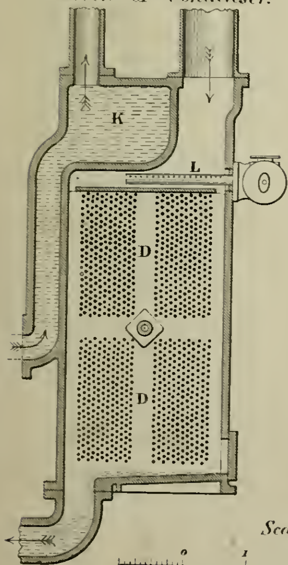


Fig. 5.

Plan of Condenser.

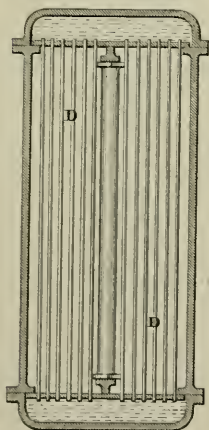
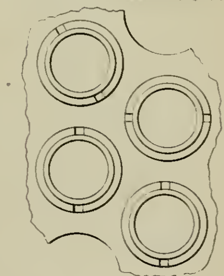


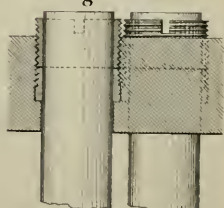
Fig. 6. *Fixing of Tubes in Condenser.*



Scale 1/36th.

0 1 2 3 4 5 *Feet.*

Fig. 7. *Plan.*



Half full size.

Fig. 8. *Vertical Section of Blowing Cylinder.*

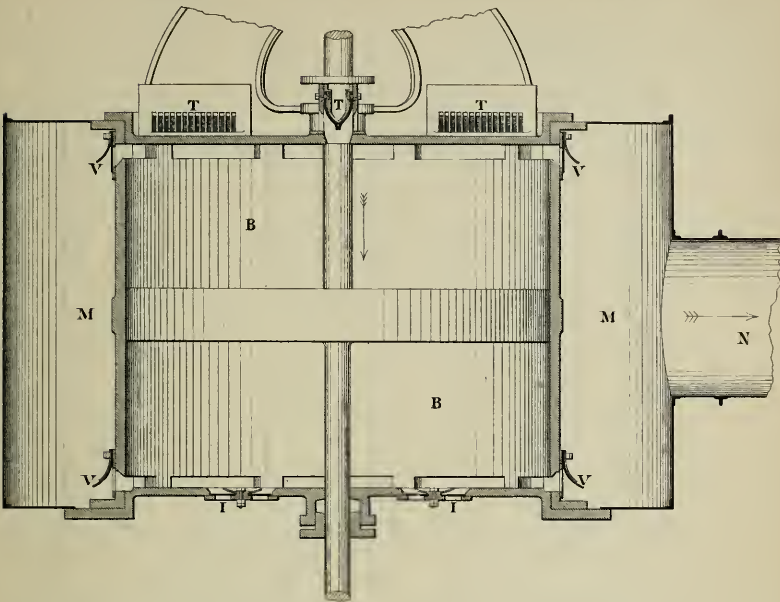
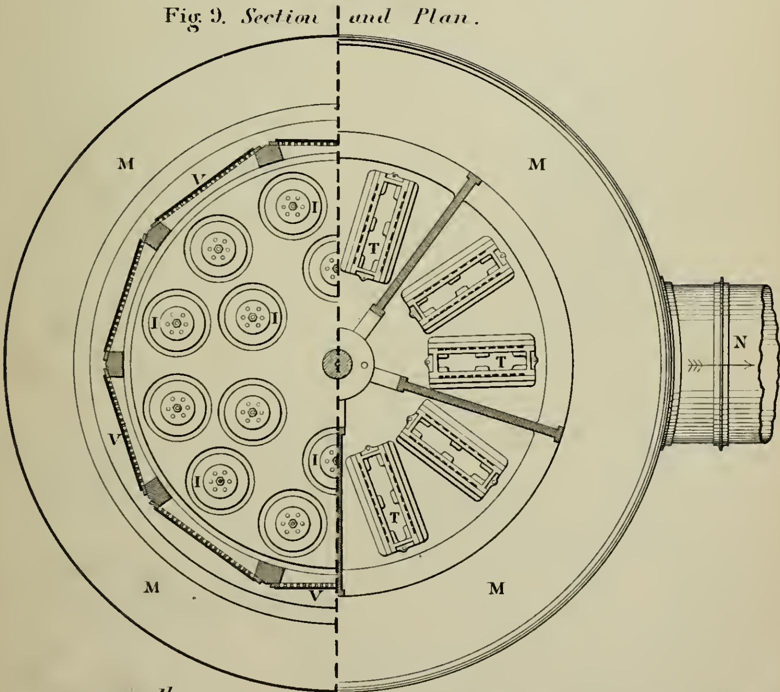


Fig. 9. *Section and Plan.*



Scale 1/36th

(Proceedings Inst. M. E. 1871.)

0 1 2 3 4 5 6 7 8 9 10 Feet.

COMPOUND-CYLINDER BLOWING ENGINES.

Plate 50.

Inlet Valves on Top of Blowing Cylinders.

Fig. 10. *Section.*

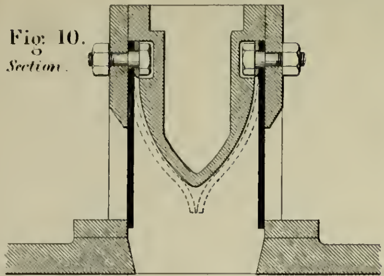
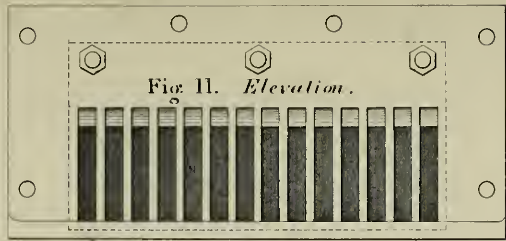


Fig. 11. *Elevation.*



Inlet Valves on Bottom of Blowing Cylinders.

Fig. 12. *Section.*

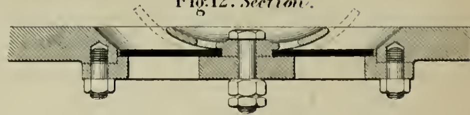
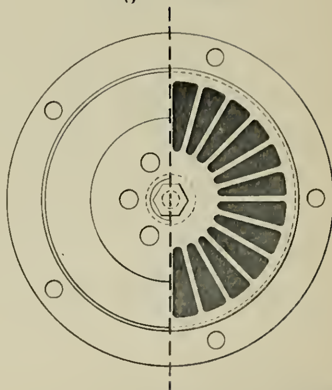


Fig. 13. *Plan.*



Outlet Valves at Top and Bottom of Blowing Cylinders.

Fig. 14. *Section.*

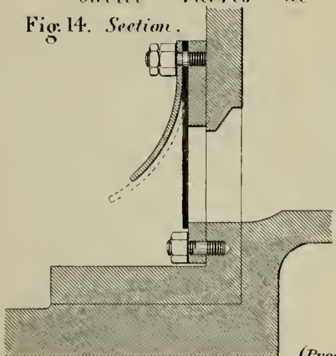
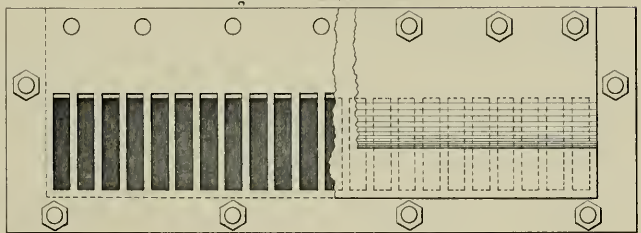


Fig. 15. *Elevation.*



(Proceedings Inst. M. E. 1871.) *Scale* 1/8th.

PROCEEDINGS.

25 and 26 July, 1871.

The Annual Meeting of the Members was held in the Oddfellows' Hall, Middlesbrough, on Tuesday, 25th July, 1871; John Ramsbottom, Esq., President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The President announced that the Ballot Lists had been opened, and the following New Members were duly elected :—

MEMBERS.

Walter Chamberlain, . . .	Birmingham.
William Crossley, . . .	Dalton-in-Furness.
Benjamin Samuel Fisher, . .	Cardiff.
Lieut. George Edward Grover, R.E.,	London.
Joseph Edward Harrison, . .	Tipton.
John Hartness, ...	Sunderland.
Joseph Holiday, ...	Bradford.
Francis Henry Lloyd, . . .	Wednesbury.
Henry William Marsh, . . .	Brigg.
Frederick Parke, . . .	Chorley.
David Rollo, ...	Liverpool.
Henry Simon, ...	Manchester.
Henry Joseph West, . . .	London.
Edward Withy, ...	Hartlepool.
William Wright, ...	Lostwithiel.

The following paper was then read :—

ON THE MANUFACTURE OF HÆMATITE IRON.

By Mr. WILLIAM CROSSLEY, of Askam-in-Furness.

In the Hæmatite district of Lancashire and Cumberland, owing to the peculiarities of the materials employed and other causes, it has not been practicable to make use of all the most recent improvements in the working of blast furnaces, or to keep pace with the rapid progress effected elsewhere; but it is thought a description of the results obtained may not be altogether out of place in a district like Cleveland, where the manufacture of iron is carried on in the most scientific manner and with the most approved appliances.

The Blast Furnaces of the hæmatite district are much the same as those at work in Cleveland, but the appliances for working them are not usually quite so good. Those at work at Barrow may be taken as a fair type of most hæmatite furnaces as to size and capacity; they are about 55 feet high and 16 feet diameter at the boshes, having a capacity of about 9,000 to 10,000 cubic feet. The furnaces at the Furness Iron and Steel Works, Askam, with which the writer is connected, are 67 feet high and 19 feet diameter at the boshes, tapering to 18 feet below the gas outlet, as shown in Figs. 1 and 2, Plate 37; and they have a capacity of 13,100 cubic feet, which the writer understands is greater than that of any other hæmatite furnaces at present working. The various attempts which have been made to work larger furnaces for hæmatite ores do not seem to have been attended with such success as to justify the erection of others; and in one or two instances where furnaces of 75 feet height have been erected, the results obtained have been so unsatisfactory that the furnaces have been blown out and the height diminished to 55 or 60 feet. The Askam furnaces of 67 feet height did not work well for some time when they were first blown in; the cause of their bad working was attributed to the smallness

of the charging bells in proportion to the width of the furnaces, and consequently larger bells were substituted. The bells at first employed were only 7 ft. 6 ins. diameter; but the present ones are 12 ft. 6 ins. diameter, as shown in Fig. 5, Plate 39, and these are believed to be the largest of any yet used for hæmatite furnaces. These furnaces now work with great regularity, and each produces weekly from 400 to 460 tons of iron, a large proportion being of a quality suitable for Bessemer converters.

The general form of these furnaces is shown in Figs. 1 and 2, Plate 37, and the principal dimensions are as follows:—

Height	67 feet.
Diameter at boshes	19 „
„ throat	18 „
„ hearth	7 „
Heating surface	5500 square feet.
Number of tuyeres	6
Area of blast inlet	75 square inches.
Pressure of blast at engine	3 lbs.
„ „ tuyeres	$2\frac{3}{4}$ lbs.
Area of gas outlet	18 square feet.
Diameter of charging bell	12 ft. 6 ins.
Weekly make of iron per furnace	400 to 460 tons.

For taking off the blast-furnace gas, the bell and hopper arrangement adopted in the Cleveland district has not been found to answer so well in the hæmatite furnaces; and the writer is informed that the Carnforth and Askam Works are the only two places at which this plan is at work in the hæmatite district. In Fig. 5, Plate 39, is shown the closed top of the Askam furnaces, with the outlet opening for taking off the waste gas. The reasons advanced for not adopting the closed-top plan at other places are—first, that it is believed to act prejudicially upon the quality of the iron produced; and secondly, that it throws a heavier back pressure on the furnaces, and thus interferes with their regular working. The first objection the writer thinks cannot be entertained without some more positive proof than has at present been advanced; and the second is met by the fact that there are hæmatite furnaces in which the closed top has been adopted with apparently perfect success, and it has not been found that increased back pressure acts prejudicially in any way,

excepting so far as it throws increased work on the blowing engines. This latter point the writer has not tested by throwing any particularly heavy back pressure on the furnaces; but he draws the conclusion from the circumstance that a furnace in which two gas outlets were provided, one of 4 ft. and the other of 5 ft. diameter, was not found to work in any way better than another furnace with only one 5 ft. outlet, all other conditions being the same. Moreover in working a furnace for eight or ten months continuously, the flues and gas outlet get gradually contracted in area, and throw a greater back pressure on the furnace, without however interfering in any way with the regularity of its working. If this experience is confirmed by the results obtained elsewhere, it is evident that some other explanation must be sought of the alleged failure of the closed-top system; and in the writer's opinion the sole explanation is to be found in an improper distribution of materials, owing to the bell not being suitably proportioned to the size of the furnace throat. In respect to this point it is better to err in having the bell rather too large, than incur any risk of its being too small.

The furnace shown in Figs. 3 and 4, Plate 38, is one at present building at Askam, which is expected to be ready for blast in a couple of months. It is 75 ft. high, 23 ft. diameter at the boshes, and has a bell 14 ft. diameter. The object in adopting these dimensions has been to ascertain whether the same advantages will result from increasing the height up to 75 feet which have been obtained in Cleveland; and the diameter of 23 feet, which is greater than that of any furnace previously built in the hæmatite district, has been decided upon under the conviction that, owing to the compact nature of the materials, it is necessary the diameter should be increased, in order to maintain regularity in the descent of the materials, and also to facilitate the upward passage of the blast, which has constituted one of the difficulties met with in high and narrow hæmatite furnaces.

The arrangement of furnace top shown in Fig. 6, Plate 39, or some modification of it, is usually adopted where the gas from open-topped hæmatite furnaces is utilised, the gas being taken off through a series of openings round the furnace throat, which is contracted

in diameter more abruptly at that part. This construction is found to answer the purpose of distributing the materials very fairly, and at the same time of taking off a large proportion of the gas to the stoves and boilers; but in the writer's opinion it can only be looked upon as a compromise, and not as a plan to be satisfied with. In Figs. 7 and 8, Plate 40, is shown the semi-closed top used at the Barrow furnaces, in which the gas is taken off through a central gas tube as well as through openings round the furnace throat.

Of the materials used in the production of hæmatite iron the principal is the hæmatite ore, found in large quantities in North Lancashire and Cumberland, and generally known as the ore of the Furness and Whitehaven districts. This ore occurs principally in two varieties, one of which is hard, compact, and almost free from moisture, while the other variety is soft and wet. The hard ore is almost invariably used in the production of hæmatite pig iron, and is therefore called blast ore; while the softer quality is used for fettling puddling furnaces, and is called puddling ore. The blast ore of Whitehaven and Furness does not differ much in quality, both districts yielding good and bad varieties; but there can be no doubt that the best Whitehaven ores are richer in iron than the best Furness ores. In Furness the poorer blast ores usually contain about 45 per cent. of metallic iron, while the better qualities run up to 57 and in some cases 60 per cent.; in Whitehaven the poorer ores contain about 50 per cent. of metallic iron, and the best run up to 60 or 65 per cent.; but the average percentage of iron in the ores used in both districts is probably between 57 and 60 per cent.

The ore used at Askam has the following composition:—

TABLE I.

Analysis of Askam Ore.

	Per cent.
Peroxide of Iron	83·00
Silica	15·50
Carbonate of Lime	trace
Moisture	1·50
	100·00
Percentage of Metallic Iron	58·10

It will be observed that the principle impurity is silica; and unlike the Cleveland and most other ores, this ore does not contain any alumina. It is therefore thought desirable at many places to mix it with aluminous ores, for the purpose of producing a better slag, and also in order to obtain greater regularity in the working of the furnace. The addition of these aluminous ores also gives the means of controlling in some measure the percentage of silica in the iron.

The aluminous ores are mostly obtained from Ireland, and are so readily accessible that they can be had at a reasonable cost. Three principal varieties of Irish ores are used in the manufacture of hæmatite iron, and these are fairly represented by the three ores known as lithomarge, red aluminous iron ore, and black nodular iron ore. The accompanying Table shows their respective composition :—

TABLE II.

Analysis of Aluminous Iron Ores.

	Lithomarge.	Red Aluminous Ore from Larne.	Black Nodular Ore from Red Bay.
	Per cent.	Per cent.	Per cent.
Silica	30·70	11·25	6·00
Alumina	27·05	35·61	20·37
Titanic acid	trace	trace	0·75
Peroxide of Iron	25·05	34·65	71·63
Protoxide of Iron	trace	noue	0·68
Magnesia and Lime . . .	1·11	trace	trace
Water of combination . . .	15·85	16·30	1·15
	99·76	97·81	100·58
Percentage of Metallic Iron .	17·53	24·25	50·67

From this it will be seen that the proportion of alumina to silica in the lithomarge is about in equal quantities, being 27 and 30 per cent., while in the aluminous ore from Larne, and the black nodular from Red Bay it is about 3 to 1; and as the red variety contains about 35 per cent. of alumina against 20 per cent. in the black nodular, it is evident that under ordinary circumstances the red variety would be

preferred; but at present the price of hæmatite ore is so much in excess of that of the Irish ores, that it becomes a matter for consideration whether it is not worth while to use the black nodular for the sake of the iron alone, a larger quantity of this ore being then required to produce a slag containing the proper proportion of alumina.

The lithomarge has been longest in use, and is preferred at some works; but the writer believes the other two varieties to be better for most purposes, because the percentage of silica in the lithomarge is so high in proportion to the alumina that a very large quantity of the ore must be used to produce any appreciable difference in the composition of the slag and in the smelting of the materials in the furnace. A still more serious objection to the lithomarge is the high percentage of moisture it contains, which must have a very injurious effect in cooling the escaping gases of the furnace, and thus increasing the consumption of fuel per ton of iron. This will be more fully seen by the following calculation. Supposing that 4 cwts. of lithomarge be used per ton of pig iron, and that this contains 15 per cent. of moisture; then 0·6 cwt. of water per ton of iron would have to be liberated from combination, vaporised, and further raised to the temperature of the escaping gases; and supposing this latter temperature be 500° Fahr., the cwt.-units of heat escaping in the form of steam will be 907. Then assuming that each cwt. of coke burnt in a blast furnace gives out 4320 Fahr.-cwt.-units of heat, it follows that 0·21 cwt. or $\frac{1}{4}$ cwt. of coke per ton of iron produced will be required to drive away the moisture from the lithomarge alone. This however is not all; for in addition to containing water of combination, lithomarge has a great attraction for moisture, and generally contains from 5 to 10 per cent. of hygroscopic water, which has also to be vaporised and raised to the temperature of the escaping gases; and if to this be added the coke requisite for melting 4 cwts. of material which can scarcely be called iron-producing, the total loss of fuel amounts to at least $\frac{3}{4}$ cwt. of coke per ton of iron made; and this means a reduced make, and therefore an increased cost not fully represented by the increased consumption of coke alone.

It will be seen that the red aluminous ore has also the disadvantage of containing usually about 15 or 16 per cent. of moisture; this not only occasions a waste of fuel, as in the case of the lithomarge, but the red ore having also a tendency to fall to powder, the contained moisture causes it then to assume a pasty condition, which leads to bad distribution of the materials in the furnace, and the ore is thus mechanically objectionable. The black nodular ore from Red Bay is free from the objection of containing combined water, and owing to the compact character of the nodules it does not so readily absorb moisture as either lithomarge or red aluminous ore; and as it contains a high percentage of iron, amounting to as much as 50 per cent. of metallic iron, with a large excess of alumina over silica, the proportions of the two being 20 and 6 per cent. respectively, it affords the means of neutralising the effect of the silica in the hæmatite ore, without increasing the consumption of fuel per ton of iron made, or diminishing the make of the furnace.

The hæmatite ore being found in a limestone formation and worked in the district, there is a plentiful supply of good and cheap limestone. That used at Askam is obtained from a neighbouring quarry at Stainton, and has the following composition:—

TABLE III.

Analysis of Stainton Limestone.

	Per cent.
Carbonate of Lime	95·00
Carbonate of Magnesia	4·20
Silica	0·50
Oxide of Iron, and Alumina	0·30
	100·00

The coke used is almost entirely obtained from the Durham coalfield, and is usually of the very best quality. The average composition of the coke used at Askam is as follows:—

TABLE IV.

Analysis of Durham Coke.

	Per cent.
Sulphur	0·70
Ash	5·00
Moisture and loss	0·92
Carbon (by difference)	93·38
	100·00

In working a material so difficult to deal with as the hæmatite ore, the first and most important point to be attended to is the proper distribution of the materials in the furnace. In the open-topped and semi-closed furnaces this is easily done by keeping the furnace always full to the same height, and putting in small charges in regular rotation. In the case of close-topped furnaces the same object is accomplished, either by taking care to have the charging bell properly proportioned to the diameter of the furnace, as previously mentioned; or else by gauging at frequent intervals with an iron rod, in order to make sure that the materials shall never be above or below the height which has been proved by experience to give the most satisfactory results. The gauging must be done not only at one but at various points round the circumference of the furnace, as it is found that there is a tendency at times to drive unequally on different sides; and this may be counteracted by regulating the supply of blast by means of a valve fixed to each tuyere. It is also necessary to prevent the ore being charged in too large pieces; otherwise it is found excessively difficult, owing to the compact nature of the ore, to ensure its perfect reduction before it reaches the part of the furnace at which it is melted.

A further difficulty is met with in keeping the tuyere-breasts good, as any fretting at these places leads to the necessity for changing the tuyeres, and consequently occasions irregularity of working in the furnace. To obviate this as much as possible, the construction of tuyere and tuyere-breast shown in Figs. 9 and 10, Plate 41, has been adopted, consisting of a close double coil of water pipe; the large outer coil A A is 14 inches diameter and of the depth

of the tuyere-breast, and in the centre of it the tuyere B is packed with clay C C; in the event of the tuyere leaking, it can then be easily removed by taking out the clay, and another tuyere can be substituted, the whole process of changing the tuyere occupying only from 10 to 15 minutes. This plan was first adopted at the Ormesby Iron Works, Middlesbrough, to protect the tuyere-breasts, which were found to work hot; and it has also been found to facilitate very much the process of changing the tuyere. As nothing interferes so much with the regularity of working of a blast furnace as trouble with the tuyere-breasts and changing the tuyeres, this simple plan has proved to be of considerable value in removing those sources of difficulty.

The result of the working of the Askam No. 2 furnace, of 67 ft. height, 19 ft. diameter, and 13,100 cubic feet capacity, has been found to be a consumption of $22\frac{3}{4}$ cwts. of coke per ton of iron made, when working on Bessemer iron and using the Askam ore mixed with about 10 per cent. of black nodular ironstone, known as Fisher's Red Bay Ore, and fluxed with $9\frac{1}{4}$ cwts. of limestone per ton of iron made. The average temperature of the blast during a considerable period of observation was 934° Fahr., and that of the escaping gases at the furnace top about 712° Fahr.

The composition of the escaping gases has been found by analysis after drying them to be as follows, at a time when their temperature was 732° Fahr., and that of the blast 968°:—

TABLE V.

Analysis of Escaping Gases from Askam Blast Furnace.

	By Volume.	By Weight.
	Per cent.	Per cent.
Nitrogen	54·51	52·59
Carbonic oxide	34·97	33·80
Carbonic acid	8·36	13·47
Hydrogen	2·16	0·14
	100·00	100·00

The weight of the escaping gases is 120 cwts. per ton of iron made, and the quantity of heat carried off by them when escaping at the temperature of 732° Fahr. amounts consequently to 22,669 Fahr.-cwt.-units, one such unit being the quantity of heat required to raise 1 cwt. of water through 1 degree of temperature Fahr. The weight of blast supplied to the furnace is $82\frac{1}{2}$ cwts. per ton of iron made, which at the temperature of 968° Fahr. introduces into the furnace 19,176 units of heat; this is in the proportion of about 85 per cent. of the heat that is carried off by the escaping gases.

The details of the production and absorption of heat in the furnace are appended to the present paper; and for the purpose of comparison with the results of the working of the Cleveland furnaces, they are given in a tabulated form similar to that employed by Mr. I. Lowthian Bell for the Cleveland furnaces. The total quantity of heat produced in the Askam furnace by the combustion of the coke and by the blast amounts to 150,000 cwt.-units per ton of iron made, of which 40 per cent. is absorbed in the actual reduction of the iron from the ore, and 15 per cent. is carried off in the escaping gases, the remainder being accounted for by the other operations taking place within the furnace.

The composition of the Bessemer and forge iron made in the furnace, and also of the slag, is given in the following Tables:—

TABLE VI.

Analysis of Askam Hæmatite Pig Iron.

	No. 1 Bessemer Iron.	No. 3 Bessemer Iron.	No. 4 Forge Iron.
	Per cent.	Per cent.	Per cent.
Carbon, uncombined	3·928	3·377	2·719
„ combined	0·109	0·469	1·222
Silicon	2·640	2·424	1·608
Aluminium	trace	trace	trace
Manganese	0·093	0·021	0·021
Calcium	0·021	0·050	0·074
Magnesium	trace	trace	trace
Sulphur	0·004	0·004	0·031
Phosphorus	0·014	0·010	0·016
Iron	93·191	93·645	94·309
	100·000	100·000	100·000

TABLE VII.

Analysis of Slag from Askam Blast Furnace.

	Per cent.
Silica	38·00
Alumina	10·00
Lime	42·19
Magnesia	1·65
Sulphuret of Calcium	2·45
Protoxide of Iron	2·08
Potash	1·60
Protoxide of Manganese	trace
Soda and loss	2·03
	100·00

The quantity of coke used—$22\frac{3}{4}$ cwts. per ton of iron made—may seem large as compared with the consumption in the Cleveland furnaces, in which, although a much poorer variety of stone is employed, the consumption of coke is not more than from 20 to $21\frac{1}{2}$ cwts. per ton of iron; but it is to be remembered that the $22\frac{3}{4}$ cwts. is the result obtained in making Bessemer iron, which requires a specially high intensity of heat. The same furnace making forge iron would work well with about 2 cwts. less coke per ton of iron; and the temperature of the escaping gases has been found to be much lower when this quality of iron is being intentionally produced.

Another point worthy of attention is the small percentage of carbonic acid in the escaping gas, amounting to only 13 per cent. This seems to indicate, either that the ore is not so easily reducible as has generally been supposed; or that, owing to its compact nature or else its bad mechanical condition, the reducing gases do not ascend with the regularity which is obtained in a Cleveland furnace, and therefore do not effect that amount of reduction in the higher and cooler part of the furnace which is favourable to the production of carbonic acid at such a temperature as to prevent its own subsequent reduction to carbonic oxide; and the very high temperature of the escaping gases from the hæmatite furnaces appears to the writer to support such a conclusion.

It is also evident from the examination of these results, that, if it be possible in the Cleveland district to get the gases evolved from the furnace at as low a temperature as 312° Fahr. (as in the very large furnaces of 105 feet height at Ferryhill), and containing as much as 15 per cent. of carbonic acid, then it follows that for the purpose of making Bessemer iron the maximum size of furnace for working with the greatest economy of fuel has not yet been reached in the hæmatite district. On the other hand it must also be remembered that the hæmatite ore is a material which is not so easily worked as Cleveland ironstone, and does not admit of that free passage of the ascending gases which is so essential to the good working of a furnace. In fact there are other questions of working to be considered in the manufacture of Bessemer iron, which are as important as economy in fuel, if not more so; and although the 75 feet furnace now building at Askam is not the first hæmatite furnace of that height which has been built, and previous steps taken in the direction of increased height have not answered the expectations raised respecting them, the writer believes there are sufficient grounds for feeling sanguine as to the success of the present attempt.

APPENDIX.

From the analysis given in Table V of the escaping gases from the Askam furnace, their ultimate composition is ascertained. The 33·80 per cent. of carbonic oxide ($CO = 6 + 8 = 14$) is equivalent to $\frac{6}{14} \times 33{\cdot}80 = 14{\cdot}49$ per cent. of carbon, with $\frac{8}{14} \times 33{\cdot}80 = 19{\cdot}31$ per cent. of oxygen; and the 13·47 per cent. of carbonic acid ($CO_2 = 6 + 16 = 22$) is equivalent to $\frac{6}{22} \times 13{\cdot}47 = 3{\cdot}67$ per cent. of carbon, with $\frac{16}{22} \times 13{\cdot}47 = 9{\cdot}80$ per cent. of oxygen. Hence the ultimate composition of the escaping gases by weight after being dried is as follows:—

TABLE VIII.

Ultimate Composition of Escaping Gases.

	Per cent.	Nitrogen.	Oxygen.	Carbon.	Hydrogen.
Nitrogen . . .	52·59	52·59	—	—	—
Carbonic oxide .	33·80	—	19·31	14·49	—
Carbonic acid . .	13·47	—	9·80	3·67	—
Hydrogen . . .	0·14	—	—	—	0·14
	100·00	52·59	29·11	18·16	0·14

The actual weight of the escaping gases per ton of iron made is arrived at by ascertaining the total quantity of carbon introduced into the furnace, and calculating from this the actual quantity passing off in the escaping gases. The consumption of coke per ton of iron made is found by actual measurement to be 22·75 cwts.; and deducting 6·62 per cent. of this = 1·50 cwt. for ash &c., in accordance with the analysis given in Table IV, the consumption of carbon is 21·25 cwts. The flux of 9·25 cwts. of limestone contains, as shown in Table III, 95·00 per cent. of carbonate of lime [$CaO, CO_2 = (20 + 8) + (6 + 16) = 50$], and 4·20 per cent. of carbonate of magnesia [$MgO, CO_2 = (12 + 8) + (6 + 16) = 42$]; and the weight of carbon contained in the limestone is therefore $\frac{6}{50} \times 95{\cdot}00 + \frac{6}{42} \times 4{\cdot}20 = 11{\cdot}40 + 0{\cdot}60 = 12{\cdot}00$ per cent. of 9·25 cwts. = 1·11 cwt. of carbon. The total weight of carbon supplied into the blast furnace per ton of iron made is accordingly 21·25 + 1·11 = 22·36 cwts. of carbon; and the analysis of the pig iron given in Table VI shows that the 1 ton of pig iron made takes up 4 per cent. = 0·80 cwt. of carbon, leaving therefore 21·56 cwts. as the actual quantity of carbon passing off in the escaping gases.

Coke used per ton of iron .	22·75		
Less ash &c.	1·50		
Carbon contained in coke . . .		21·25 cwts.	Carbon available for heat production. 20·14 cwts.
Do. do. limestone . .		1·11 ,,	
Total Carbon in coke and limestone .		22·36 ,,	
Less carbon taken up in pig iron . .		0·80 ,,	
Carbon carried off in escaping gases .		21·56 cwts.	

As the quantity of carbon carried off in the escaping gases has already been seen in Table VIII to form 18·16 per cent. of their weight when dried, it follows that the total weight of the escaping gases per ton of iron made is $100{\cdot}00 \times \frac{21{\cdot}56}{18{\cdot}16} = 118{\cdot}72$ cwts. when dried; and the weight of their several constituent elements is in the same way ascertained to be as given in the following Table IX. The ore charged into the furnace contains about 1·00 cwt. of water, and the coke 0·58 cwt., making together 1·58 cwt. of water, which is simply evaporated without being decomposed, and passes off as steam in the escaping gases; their total weight on leaving the furnace top is therefore 120·30 cwts. per ton of iron made.

TABLE IX.

Actual Weight and Composition of Escaping Gases per ton of iron made.

	Cwts.	Nitrogen.	Oxygen.	Carbon.	Hydrogen.
Nitrogen	62·44	62·44	—	—	—
Carbonic oxide . . .	40·13	—	22·93	17·20	—
Carbonic acid	15·99	—	11·63	4·36	—
Hydrogen	0·16	—	—	—	0·16
Steam (not decomposed)	1·58	—	—	—	—
Total weight of gases .	120·30	62·44	34·56	21·56	0·16

The weight of the blast supplied to the furnace can now be ascertained, as this will contribute the whole amount of the nitrogen contained in the escaping gases, 62·44 cwts., which will be accompanied by $\frac{23}{77} \times 62{\cdot}44 = 18{\cdot}65$ cwts. of oxygen, and also by $0{\cdot}16 \times 9 = 1{\cdot}44$ cwt. of moisture in the air, giving 82·53 cwts. as the total weight of blast supplied per ton of iron made.

Nitrogen	62·44 cwts.
Oxygen	18·65 ,,
Moisture	1·44 ,,
Weight of Blast per ton of iron made	82·53 cwts.

The heat contributed by the 82·53 cwts. of blast at the temperature of 968° Fahr. (520° C.) is as follows, taking the specific heat of air as 0·24, that of water being 1·00:—

Heat contributed by blast = 82·53 × 0·24 × 968 = 19,176 Fahr.-cwt.-units.

The heat carried off by the 120·30 cwts. of escaping gases at the temperature of 732° Fahr. (389° C.) is as follows, taking their specific heat to be the same as that of air 0·24, and adding the latent heat in the 1·58 cwt. of steam:—

Sensible Heat in gases = 120·30 × 0·24 × 732 =	21,133	Fahr.-cwt.-units.
Latent Heat in steam = 1·58 × 1·00 × 972 =	1,536	„
Total Heat carried off in escaping gases	22,669	„

In the following Tables X and XI is given an estimate of the *heat produced* and also of the *heat absorbed* per ton of iron made in the Askam No. 2 furnace, of 67 feet height, 19 feet diameter, and 13,100 cubic feet capacity, with the consumption of 22·75 cwts. of coke, and with a flux of 9·25 cwts. of limestone. In the estimate of the heat produced, the quantity of carbon available for the furnace work is rather less than the whole weight of carbon 21·25 cwts. supplied in the coke, because the carbonic acid in the limestone containing 1·11 cwt. of carbon requires another equal quantity of carbon for its reduction to carbonic oxide ($CO_2 + C = 2CO$), thus leaving only 20·14 cwts. as the quantity of carbon available for heat production. In the estimate of the heat absorbed, the latent heat of the steam in the escaping gases is taken into account as part of the furnace work, under the head of evaporation of the water contained in the ore and coke; consequently the item of the heat carried off in the escaping gases includes here only their sensible heat. As the ores used do not contain any sulphur, no item appears for expulsion of sulphur; the small percentage found in the pig iron, as shown in Table VI, is therefore obtained from the coke, in which it probably exists as sulphide of iron. Table X gives the estimate in Fahrenheit-cwt.-units, and the corresponding Centigrade-cwt.-units are given in Table XI.

TABLE X.

Production and Absorption of Heat per ton of iron made, in Fahrenheit-cwt.-units.

HEAT PRODUCED.

	cwts.		Fahr. units.
Combustion of 20·14 cwts. of carbon into carbonic oxide	20·14 ×	4320 =	87,005
Further combustion of 4·36 cwts. of above carbon into carbonic acid	4·36 ×	10080 =	43,848
Heat introduced by Blast			19,176
Total Heat Produced			150,029
Difference			3,187
			153,216

HEAT ABSORBED BY FURNACE WORK.

	cwts.		Fahr. units.	
Evaporation of 1·00 cwt. of water from ore	1·00 ×	970 =	970	
Evaporation of 0·58 cwt. of water from coke	0·58 ×	970 =	563	
Impregnation of pig iron with 0·80 cwt. of carbon from carbonic oxide	0·80 ×	4320 =	3,456	
Expulsion of carbonic acid from 9·25 cwts. of limestone	9·25 ×	670 =	6,197	
Reduction to carbonic oxide of the above carbonic acid containing 1·11 cwt. of carbon (10080 − 4320 = 5760 units)	1·11 ×	5760 =	6,394	
Reduction of 18·60 cwts. of iron from peroxide (93 per cent.* of 20 cwts. = 18·60 cwts.)	18·60 ×	3200 =	59,520	
Decomposition of moisture in blast, containing 0·16 cwt. of hydrogen	0·16 ×	61200 =	9,792	
Reduction of 0·52 cwt. of silicon from silica (2·6 per cent.* of 20 cwts. = 0·52 cwt.)	0·52 ×	14400 =	7,488	
Fusion of 20 cwts. of pig iron	20·00 ×	590 =	11,800	
Fusion of 15 cwts. of slag	15·00 ×	990 =	14,850	
Total Heat Absorbed by furnace work				121,030

LOSS.

Transmission through walls of furnace	7.781	
Carried off in tuyere water	3,272	
Carried off in escaping gases	21,133	
Total Heat Escaping from furnace		32,186
		153,216

(* See Table VI.)

TABLE XI.

Production and Absorption of Heat per ton of iron made, in Centigrade-cwt.-units.

HEAT PRODUCED.

	cwts.	Cent. units.
Combustion of 20·14 cwts. of carbon into carbonic oxide	20·14 × 2400 =	48,336
Further combustion of 4·36 cwts. of above carbon into carbonic acid	4·36 × 5600 =	24,360
Heat introduced by Blast		10,300
Total Heat Produced		82,996
Difference		1,680
		84,676

HEAT ABSORBED BY FURNACE WORK.

	cwts.		Cent. units.	
Evaporation of 1·00 cwt. of water from ore	1·00 ×	540 =	540	
Evaporation of 0·58 cwt. of water from coke	0·58 ×	540 =	313	
Impregnation of pig iron with 0·80 cwt. of carbon from carbonic acid	0·80 ×	2400 =	1,920	
Expulsion of carbonic acid from 9·25 cwts. of limestone	9·25 ×	370 =	3,422	
Reduction to carbonic oxide of the above carbonic acid containing 1·11 cwt. of carbon (5600 − 2400 = 3200 units)	1·11 ×	3200 =	3,552	
Reduction of 18·60 cwts. of iron from peroxide (93 per cent.* of 20 cwts. = 18·60 cwts.)	18·60 ×	1780 =	33,108	
Decomposition of moisture in blast, containing 0·16 cwt. of hydrogen	0·16 ×	34000 =	5.440	
Reduction of 0·52 cwt. of silicon from silica (2·6 per cent.* of 20 cwts. = 0·52 cwt.)	0·52 ×	8000 =	4,160	
Fusion of 20 cwts. of pig iron	20·00 ×	330 =	6,600	
Fusion of 15 cwts. of slag	15·00 ×	550 =	8,250	
Total Heat Absorbed by furnace work				67,305
LOSS.				
Transmission through walls of furnace			4,323	
Carried off in tuyere water			1,818	
Carried off in escaping gases			11,230	
Total Heat Escaping from furnace				17.371
				84,676

(* See Table VI.)

Mr. C. Cochrane remarked that for making forge iron the consumption named in the paper of $20\frac{3}{4}$ cwts. of coke per ton of iron appeared to him rather high, and with the Askam ore containing 58 per cent. of metallic iron he should have expected 17 or 18 cwts. of coke would be sufficient. The desirability of having blast furnaces so high as 75 feet was an important question now occupying attention in the hæmatite district, where no greater height than 55 feet had yet been generally adopted; the previous endeavours to work the higher furnaces he believed had generally proved unsatisfactory hitherto, and he understood that in one case a furnace of 75 feet height had subsequently been cut down to 61 feet: in that instance it was to be regretted that the charging bell had not been enlarged in diameter to the extent recommended in the paper. One great difficulty in the working of the hæmatite furnaces had been the liability to "scaffolding," and he understood the high furnace had been found liable to "hang" altogether for periods of ten or twelve hours at a time, during which it did not "drive" at all. The scaffolding was no doubt accounted for in a great measure by the small size and peculiar nature of the ores worked in the hæmatite furnaces, as explained in the paper, causing the ascending gases to carve out local passages for themselves in different directions, instead of ascending uniformly through all parts of the large area of the furnace; and he hoped to hear that with increased height of furnaces means were found for obviating these difficulties in the working.

Mr. W. Clay enquired whether there was any difficulty in obtaining a sufficient quantity of gas from the Askam furnaces for heating the steam boilers. At the Millom Iron Works in the same district, with which he was connected, the quantity of gas obtained from four semi-closed furnaces was not sufficient for all the boilers and stoves, two or three of the boilers having to be fired with coal; but in the Cleveland district there was always a surplus of gas from the furnaces, beyond what was wanted for the stoves and for firing the boilers. With regard to scaffolding, the experience at Millom had been that this was generally partial, the furnace having been sometimes found to "hang" at one side, which was attributed

to a cold wind blowing at the time on that side. When a scaffolding took place, the furnace would go on working in an unsatisfactory manner in consequence for several days at a time, before it would come right again.

Mr. Crossley believed the explanation suggested in the paper as to the cause of scaffolding in the hæmatite furnaces was the correct one, namely the very small size of the ore put into the furnaces, in consequence of which it was apt to get deposited somewhat unequally in different parts of the furnace and prevent the regular ascent of the gases at those parts. In this way the material probably became cemented together into large pieces, which came down on the boshes and then produced "scaffolding." He had not had any experience of a scaffolding lasting for days together, as had been alluded to in other hæmatite furnaces; in some instances he had known scaffoldings last for twelve or even eighteen hours, but a slip had then taken place and the furnace had righted itself within a remarkably short time. This was one difference between the hæmatite and the Cleveland furnaces, the latter being a considerable time in recovering themselves after a scaffolding of any considerable duration; whereas he had found in the hæmatite district, as soon as the slip had taken place, the furnace would in a very few hours be working again with its wonted regularity.

The President enquired what was considered to be the reason of the failure of the hæmatite furnace which had been referred to as having been reduced in height.

Mr. Crossley said the furnace referred to was one of 75 feet height, recently built at the Barrow Iron Works, the diameter at the boshes being only the same as in the furnaces of 67 feet height at Askam, namely 19 feet; and the difficulties experienced in that case were to be attributed he considered to not increasing the diameter in proportion to the height, and also to using a much smaller charging bell than was suitable for so high a furnace. The difficulties attending the compact nature of the hæmatite ore were thus increased by the want of greater area of open space in the furnace for ensuring the uniform passage of the ascending gases between the pieces of the materials in all parts of the furnace; and

the effect of the narrow furnace was to cause the gas to creep up at the sides of the furnace or any other part which might happen to be rather more open than the rest.

Mr. T. Whitwell mentioned that the Consett Iron Co. in the county of Durham had put up about four years ago a close-topped furnace of 70 feet height, for working a close and rich mixture of ore similar to that described as used at Askam. The Consett furnace was 20 feet diameter at the boshes, with a charging bell of 10 ft. 6 ins. diameter; and it was tried with a mixture of one third hæmatite ore from the Whitehaven district and two thirds Cleveland ore, and afterwards with a mixture of hæmatite ore and forge cinder averaging 56 per cent. of metallic iron. The pressure of the blast was 4½ lbs. per square inch, and the temperature 850° Fahr. The furnace however did not work well, and left off driving for upwards of ten days; the attempt had therefore to be abandoned, and the height of the furnace had been cut down 15 feet, leaving it 55 feet high, when it worked well on the mixture that it had previously refused. He understood that an open-topped furnace of 70 feet height had been put up at the West Cumberland Hæmatite Iron Works, Workington, in which the gas was taken off through a centre tube inserted in the furnace throat, so as to admit of seeing the level of the materials in the furnace and ensuring the charging being done with regularity; the temperature of the blast was 750° to 800°, and the pressure 4½ lbs. The furnace was intended to make Bessemer iron, and began by making a little grey; but it did not do well and soon went down to white iron, after which it could not be got back again to grey. After a year's unsuccessful trial it had had to be cut down to the height of the other furnaces in the district, namely 55 feet, and at that height it was now working well, making Bessemer iron. The last attempt which had been made at working a hæmatite furnace of more than the ordinary height was the one at the Barrow Iron Works that had been referred to, with a furnace of 75 feet height and 19 feet diameter at the boshes, having a charging bell 10 ft. 6 ins. diameter; but the furnace not being found to work well had since been reduced to 61 feet height.

The consumption of coke per ton of iron made in the Askam furnaces seemed to him high, inasmuch as at the furnace at Consett, of 55 feet height and 20 feet diameter at the boshes with a charging bell 10 ft. 6 ins. diameter, the consumption was only $17\frac{1}{2}$ cwts. over a period of six months, the furnace producing 400 tons of iron per week, of which 84 per cent. was grey forge iron, while the quantity of white iron did not exceed 2 per cent., and in one instance no white iron was made for a period of more than 26 weeks. A larger furnace had also been subsequently erected at Consett, of 22 ft. 6 ins. diameter at the boshes and 20 ft. 6 ins. diameter at 9 feet below the charging plates, with a 12 ft. 6 ins. bell; this furnace however took about 2 cwts. more coke per ton of iron, and the reason appeared to be that the upper part of the furnace was too large, and it was accordingly intended to alter it by making the lining taper from 22 ft. 6 ins. diameter at the boshes to 15 feet at the top just below the bell, that being the size of furnace which had given the best results. Considering that at Consett, with 1350° temperature of blast and a material containing only 48 per cent. of metallic iron, 84 per cent. of grey forge iron had been made without interruption during a period of more than six months, with a consumption of only $17\frac{1}{2}$ cwts. of coke per ton of iron, he did not understand how it was that the furnaces at Askam, using a richer material containing 58 per cent. of metallic iron, should require so much as $20\frac{3}{4}$ cwts. of coke per ton to make grey forge iron. It was also curious that, while the temperature of the escaping gases from the Consett furnace of 55 feet height was 478° Fahr. with the blast supplied at 1350°, the temperature of the gas from the Askam furnaces of 67 feet height was as much as 730°, though that of the blast was not more than 970°.

Mr. E. Barton observed that, in reference to the short supply of gas which had been mentioned as being obtained from hæmatite furnaces, he thought this must be owing to some fault in the construction and working of the gas apparatus, irrespective of the closed-top system; he did not see why a close-topped hæmatite furnace should not work as well as a close-topped Cleveland furnace, and the latter always yielded an ample supply of gas for

all beating purposes. At the Carnforth Iron Works, near Lancaster, they had five close-topped hæmatite furnaces, from which abundant gas was obtained, and no coal whatever was used for either boilers or stoves. The charging bells in these furnaces were 8 feet diameter, the furnaces themselves being built with a parallel throat 12 feet diameter for a depth of 10 feet from the charging level, instead of being narrowed in at the top as was usually the case. The parallel throat he considered a decided advantage, enabling the full benefit to be obtained of regularity in charging a close-topped furnace, as the materials then descended uniformly in the order in which they were charged, and he attributed to this cause the very successful working of the Carnforth furnaces; but when the throat expanded from the top downwards, the materials had to spread themselves laterally as they descended, and thus their original uniform distribution when charged into the furnace became interfered with as soon as ever they began to sink lower in the throat of the furnace. With regard to consumption of coke, he thought the consumption stated in the paper of $22\frac{3}{4}$ cwts. per ton of iron would be a large quantity, if the ore contained as much as the 58 per cent. of metallic iron that had been named; but the mixture actually employed of hæmatite and Irish ores seldom contained more than 50 per cent. of metallic iron, the usual charge in the Carnforth furnaces being nearly 2 tons of ore to make 1 ton of iron; and with that proportion the consumption of coke did not appear to him extravagant in reaching $22\frac{3}{4}$ cwts. per ton.

Mr. Crossley said that, in regard to the deficiency of gas from the Millom furnaces, he did not think the gas given off from the hæmatite furnaces was less valuable or less in quantity in proportion to the blast used than was the case in the Cleveland district; but at the Millom Works the furnaces were only semi-closed, and therefore a large quantity of gas escaped at the furnace top, representing of course so much fuel lost. At Askam they had not sufficient gas to heat the blast and raise the steam for the blowing engines, and were consequently obliged to use coal for firing the boilers. This was owing however, not to a poor or insufficient supply of gas from the furnaces, but to the faulty construction of

the blowing engines. By introducing a condensing engine the consumption of coal had already been reduced to half what it was some months ago, and he hoped to make such alterations in the blowing and steam cylinders of the present engines as would result in dispensing entirely with the use of coal.

Mr. D. Adamson remarked that it was important to enquire, in connection with the failure of high hæmatite furnaces, whether they had had the advantage of all the conditions essential for properly working a close and dense ore such as the hæmatite; and one consideration of primary importance was the pressure of blast in both the high and the low furnaces. If it were attempted to work a hæmatite furnace of 75 feet height with no greater pressure of blast than was employed in a furnace 55 feet high, it could not be expected that the gases would pass up so vigorously through the materials in the higher furnace as in the lower. In two hæmatite furnaces of 70 feet height the pressure of the blast had been stated to be $4\frac{1}{2}$ lbs. per square inch; and if in other high furnaces the blast pressure was not sufficient to ensure the efficient passage of the gases through all parts of the furnace, he thought it was not the height of the furnace that was at fault, but the want of proper mechanical arrangements for supplying the requisite pressure of blast. In his own experience he had found that, in addition to all the other conditions necessary to be observed for working ores charged in small pieces, the pressure of the blast must be increased in proportion to the density of the ore or its degree of closeness in the furnace. Irregularity of charging was also a source of difficulty in the working of high furnaces; for if the coke and limestone were charged in large pieces at one side of a furnace, whether high or low, and the ore in small pieces at the other side, the materials would descend more rapidly on the more open side, and would cause the other side to "hang;" and any difficulty from this source was of course augmented in the higher furnaces, though due not to their height but to want of proper care in charging the materials with regularity all round the furnace.

The slag from the Askam furnaces making Bessemer iron appeared to him to be carrying with it a large surplus quantity of

lime, the analysis showing 38 per cent. of silica, 10 per cent. of alumina, and as much as 42 per cent. of lime; and he thought for a good fluid slag the proportion of lime should be considerably less, not exceeding 28 or 30 per cent. For by a comparison of a great number of different slags, obtained from blast furnaces in different districts when working well, he had come to the conclusion that the proper proportions of lime, silica, and alumina were attained, when the percentage of lime was equal to the sum of the alumina and half the silica; and this agreed very nearly with what was given in the analysis of slags by Mr. Truran and Dr. Percy as the composition of a free-melting cinder. The slag produced at the Harrington furnaces, near Workington, when working well, contained in samples that had come before him 44 per cent. of silica, 13 per cent. of alumina, and 36 per cent. of lime, which very closely agreed with the above proportion, since $13+\frac{44}{2}=35$ per cent. of lime. According to this proportion the percentage of lime for the Askam slag would be $10+\frac{38}{2}=29$ per cent. of lime, showing the slag to contain at present 13 per cent. excess of lime, thereby loading the furnace with an increase of dead burden and injuring the heating power of the gas by the production of an undue quantity of carbonic acid. In South Staffordshire the proportion he had named was very closely adhered to, the slag from the furnaces in that district having very generally an approximate composition of about 40 per cent. of silica, 10 per cent. of alumina, and 30 per cent. of lime, when working native materials. If the same proportions were more carefully followed in regulating the charges of blast furnaces generally, by not allowing an excess of lime, he believed the result would be to keep the hearth in order, and neither choke the furnace with an excess of lime, nor run off the metal in the state of white iron.

Mr. J. B. Pease observed that the furnace of 70 feet height at the West Cumberland Hæmatite Iron Works, which had been referred to, could hardly be adduced as a fair example of the working of a hæmatite furnace of that height, because the circumstances under which the attempt was made in that case were exceptional and unfavourable to a successful result. The furnace had originally

been built only 55 feet high, and 17 ft. 6 ins. diameter at the boshes, and was closed by a charging bell only 6 ft. 9 ins. diameter, which was too small a size to enable the furnace to work satisfactorily. It was subsequently raised to 70 feet, for which height the diameter of 17 ft. 6 ins. at the boshes was probably too small. Moreover the steam lift by which the furnaces were fed being only 55 feet high, the materials had to be raised from the gallery of the lift by special apparatus to the top of the higher furnace, and it was found this could not be done quickly enough for charging the furnace with sufficient rapidity to enable it to turn out the work expected. Another reason why it failed was that a different material was used in this furnace, the product being intended for another purpose, and the working was not satisfactory. The increased height was therefore abandoned, and the furnace cut down again to its original height of 55 feet; but he had no doubt a hæmatite furnace of 70 to 75 feet height would succeed as well as the lower furnaces working the ore of the Whitehaven district; and that a high furnace with closed top would be worked satisfactorily and with more economy than with the open top usually adopted in furnaces working that ore. In regard to the difficulty which had been alluded to of securing proper charging of the limestone, the general practice in Cleveland was to calcine the whole of the ore before it entered the furnace, and in some cases the limestone also was charged into the calcining kiln together with the ironstone, which produced a better mixing of the materials than could be attained when the limestone was charged raw into the furnace. This was the plan introduced at the Tees Iron Works, Middlesbrough, where it had been found successful.

Mr. D. Adamson enquired whether any explanation could be given of the difference between the Carnforth and the Millom furnaces in respect to the supply of gas obtained from them. At Carnforth he believed condensing engines were employed, and if those at Millom were non-condensing they would no doubt require one third more gas for raising steam than the condensing engines; which might account for the deficiency of gas in the one case,

without any material difference existing in the working of the furnaces themselves.

Mr. W. Clay replied that not much coal was required to be used for the boilers at the Millom furnaces, but the deficiency of gas could not be accounted for by the construction of the engines, as they were condensing engines of the best kind, with cylinders 104 inches diameter. There were only five boilers working at once, two or three of which were fired with coal, and the others as well as all the hot-blast stoves were fired with gas. Perhaps the high temperature of blast obtained in the stoves, amounting to 900° Fahr., might partly account for there not being gas enough for all the boilers; and another reason might be the fact of the furnaces being only semi-closed.

Mr. I. Lowthian Bell observed that, with regard to the question of the height of blast furnaces, there could be no doubt that great height in the abstract was a disadvantage to all furnaces, because greater difficulty was necessarily encountered in forcing the blast through the greater height of superincumbent materials in a high furnace than in a low one. On the other hand, in order to avoid waste of fuel, a certain altitude of furnace was necessary for extracting the sensible heat from the escaping gases, and for deoxidising the ore in the higher parts of the furnace, before it came down into the hearth. It was indispensable that the gases should be allowed to remain in contact with the ore until these objects had been effected, and the time required for reducing one kind of ore was different from that necessary for another. The Cleveland ironstone being particularly refractory was among the last to succumb to the action of the gases, and consequently required to be worked in the highest furnaces. In some of the Styrian charcoal furnaces on the contrary, those at Eisenerz for instance, the ore charged in at the top of the furnace gave in $4\frac{1}{2}$ hours afterwards excellent grey forge iron, with a consumption of only 13 or 14 cwts. of charcoal per ton, the height of the furnaces being only from 35 to 40 feet. This was attributable not to any particular advantage in the use of charcoal, for 1 lb. of Durham coke was worth 1 lb. of the

best charcoal ever made for furnace work, and it was a mistake to imagine that charcoal was a nearer approach to pure carbon than coke was, the fact being that the purest charcoal employed for smelting iron contained generally about 15 per cent. of foreign matter. But the rapid smelting in the Styrian furnaces was due to the circumstance that the ore under treatment was very much more susceptible to reduction than either the Cleveland ore or the hæmatite of the Cumberland district, being a rich spathose ore, containing 50 per cent. of iron; it was indeed very similar in point of richness to the particular mixture of hæmatite ore that was used at Carnforth. The question therefore had to be determined by actual experience in each case, as to what was the height of furnace required for each variety of ore; and while the object was to arrive at such a height as would enable the furnaces to perform their required work with the least consumption of fuel, it was important, if height was in itself an evil though a necessary one, to take care that the proper limit of height was not exceeded, because every foot above the height absolutely required was a clear disadvantage. From information obtained respecting the working of the hæmatite furnaces, his own opinion was that about 55 feet height would be found sufficient for their duty. With regard to the cause of scaffolding, which had been attributed to the gases ascending more readily through certain portions of the furnace and leaving the materials to accumulate in other parts, this was an explanation which might apply to particular cases; but he did not think the origin of scaffolding had yet been ascertained with anything like certainty in the majority of instances of its occurrence. In respect to the consumption of fuel in blast furnaces, as affecting the quantity of gas that could be obtained from the furnace for heating purposes, the latter was in direct proportion to the quantity of fuel burnt, and was therefore reduced with any diminution in the consumption of fuel; but at the same time there was a corresponding diminution in the requirements for which the gas was wanted, as regarded both the quantity and the temperature of the blast; and he accordingly considered it was a matter of indifference whether a

rich or a poor ore was being worked, as in either case, within certain limits, the gas evolved from the furnace would be found sufficient for raising the necessary supply of steam and heating the blast to the required temperature.

Mr. Crossley said he quite concurred in the remarks which had been made as to the high hæmatite furnaces never having been tried previously under all the conditions necessary for the successful working of furnaces of that height. But because under circumstances more or less unfavourable the high furnaces had hitherto failed in the hæmatite district, it was not reasonable to infer that they would always fail; and on the contrary he believed that, when the conditions necessary for their good working were duly observed, it would be found that the larger furnaces would be attended with the same advantages and good results in the hæmatite district as had been the case in Cleveland. For at the present Askam furnaces of 67 feet height, using $22\frac{3}{4}$ cwts. of coke per ton of Bessemer pig, the temperature of the escaping gases was as high as 730° Fahr., and they contained only 13 per cent. of carbonic acid, the materials, both ore and limestone, being charged cold into the furnace, without having been calcined; whereas in the Ferryhill furnace of 105 feet height, it had been found possible to reduce the temperature of the escaping gases to 312° Fahr. with an increase of carbonic acid to 15 per cent., which was due solely to the greater height of the furnace. With these results in the Cleveland district he was led to infer that larger hæmatite furnaces would similarly be attended with considerable advantages in increased economy of fuel, resulting from reduction in the temperature of the escaping gases and increase in the proportion of carbonic acid which they contained.

The President was sure it would be generally agreed that the attempt now being made by the author of the paper to introduce into the hæmatite district the higher furnaces which had been found so advantageous in Cleveland was most praiseworthy; he trusted the efforts to effect thereby an increased economy of fuel in the manufacture of iron would be attended with the success which they

deserved, and he hoped the results of the working of the higher furnaces would be communicated on a future occasion.

He proposed a vote of thanks to Mr. Crossley for his paper, which was passed.

The following paper was then read :—

ON THE PRELIMINARY TREATMENT OF THE MATERIALS USED IN THE MANUFACTURE OF PIG IRON IN THE CLEVELAND DISTRICT.

By Mr. I. LOWTHIAN BELL, of Middlesbrough.

The three Raw Materials employed in the production of pig iron contain each a certain portion of volatile matters in combination. In the Cleveland district the Fuel, obtained from the collieries of South Durham, is made up of fixed carbon and ash, combined with about 35 per cent. of substances which, when the raw coal is submitted to heat, escape chiefly in the form of combustible compounds of hydrogen and carbon. The Ore contains about 28 per cent. of earthy substances, associated with about 31 per cent. of metallic iron, chiefly in the form of carbonate of the protoxide; in this case carbonic acid and oxygen, together with some water, constitute the volatile portions. The Flux is carbonate of lime almost pure, containing therefore 56 per cent. of the caustic lime united to 44 per cent. of carbonic acid. Whatever be the condition in which these substances are delivered into the blast furnace, the whole of the volatile portions referred to, namely the hydrocarbons of the coal and the carbonic acid and water of the ore and limestone, are expelled long before the process of smelting is complete. This expulsion means work and absorption of heat; and hence the usual practice has been to perform the operation in apparatus of a less costly kind than a blast furnace, and by means of a less expensive class of labour than that required for completing the smelting process itself. Accordingly for separating the hydrocarbons from the coke, different forms of coke ovens are employed, some of which are shown in Plates 42, 43, and 44; and for depriving the ironstone or flux of its carbonic acid, a calcining kiln is used, as shown in Plate 45, in which the raw ore is introduced with a small quantity of the cheapest kind of small coal.

As the volatile portion of the coal is highly inflammable, and weight for weight has a much greater heating power than the fixed carbon or coke portion, it will be understood that there is ample ground for the regret often expressed at the loss of a quantity of heating material, which on the make of pig iron in this district may be taken as equivalent to one million tons of coal per annum. The value of this quantity of fuel cannot be less than £250,000 at the pit mouth, and therefore represents something like 4*s*. per ton on all the pig iron manufactured by means of Durham coke from Cleveland ore.

The volatile matters found associated with the metal in the ironstone are carbonic acid and oxygen, with a trace of sulphur and a notable quantity of water. The sulphur, or at least that which exists as bisulphide of iron, may be entirely expelled from the iron by heat; but it is not improbable that a portion of the resulting sulphurous acid may be taken up by the lime which exists in the ore. The water is entirely driven off, and shows itself in clouds of steam at the top of the calcining kiln. The carbonic acid united with the iron is likewise entirely dissipated when the operation is properly conducted; a trace however is usually found in the calcined Cleveland ore, which is probably in the form of carbonate of lime or magnesia. As regards the oxygen, this element not only remains undiminished in respect to quantity, but the iron passes into the state of peroxide, taking up one half more oxygen than that originally existing in the ironstone.

Two modifications of the present process of treating the ironstone have recently been recommended for adoption in the Cleveland district. The one has for its object to expel by preliminary treatment not only the carbonic acid and water, but also the oxygen of the oxide of iron, leaving the blast furnace nothing to do but to fuse the metal and slag. The other idea is of older date, and consists in introducing the ironstone raw into the blast furnace, as it comes from the mines. As regards the limestone, this in the greater number of cases is used in its raw state; in others the carbonic acid and moisture are driven off by calcining, and the flux is employed in the form of quick lime. In the present paper the writer purposes,

by considering the nature of the operation of smelting as it is effected in the blast furnace, to enquire what the condition of the materials ought to be at the period of their being charged in at the top, and therefore what benefit is likely to result from any modifications of the present process.

Whatever is the condition of the fuel when charged into the furnace, whether coked or in the state of raw coal, by the time it arrives at the tuyeres, where it is burnt before the blast, all the volatile portions will have been expelled by the high temperature already encountered in its descent through the furnace. The duty of the heat evolved in the hearth of the blast furnace may be regarded as being to fuse the reduced iron, in which operation the metal absorbs a certain portion of carbon, silicon, &c.; and at the same time to reduce to the liquid state all the earthy constituents of the fuel, ironstone, and flux. It will therefore be assumed for the present that the entire operation to be accomplished in the blast furnace consists in the fusion of the iron and the slag, the fuel being regarded as perfect coke, the ironstone as reduced metal and earthy matter, and the flux as pure caustic lime; the generation of a certain quantity of cyanogen (C_2N) will be left out of view, as unimportant for the present purpose.

The blast entering at the tuyeres and meeting the heated carbon in the furnace is instantly resolved into carbonic oxide, which gas along with the nitrogen of the blast acquires the same temperature as the solid contents of the bottom of the furnace. An immense volume of gaseous matter, about double the weight of the coke, iron, and slag which it meets, rushes upwards with great velocity from the lower part of the furnace, carrying away with it a very large proportion of the heat evolved by the combustion of the carbon. To prevent the loss which would ensue were this large bulk of heated gases to escape into the air, the blast furnace is required to have a certain altitude, in order that the descending mass of solid cold material may absorb the heat contained in the ascending stream of gas, which heat is thus carried down again to the hearth and is thereby made available for the melting process proper to that

region. Supposing no heat to escape at the furnace top, that is, supposing the gases from a furnace engaged in simple fusion were to pass off at the temperature of the atmosphere, which may be regarded as that of the materials, it is obvious that just as much fuel would be consumed at the tuyeres as is absolutely required to melt the slag and iron and to provide for the inevitable loss by radiation &c.

If, instead of introducing the fuel in the form of coke, it be employed in the state of raw coal, the volatile matter it contains will first have to be expelled in the blast furnace; for the condition of the furnace in respect to temperature renders it impossible that the coal can reach the only part of the furnace where its heat is available, without previously giving off its hydrocarbons. But the solid carbon burnt at the tuyeres has already had assigned to it the full measure of work it is capable of performing; and hence, to provide for that quantity of heat which in gas works is obtained by the combustion of fuel under the retorts, more coke must be burnt at the tuyeres. As therefore the gas itself is not profitably employed, and as it is expelled in the upper portion of the furnace at the cost of a certain quantity of heat, it follows as a necessary consequence that when raw coal is employed a somewhat greater weight will be needed than that containing the actual quantity of fixed carbon required at the tuyeres for melting the slag and iron &c.

In a coke oven the expulsion of the volatile constituents of the coal is effected by their own combustion, which as already seen is not the case when the coal is charged raw into the blast furnace. Hence if a form of coke oven were employed in which there was no loss of fixed carbon in the process of coking, the actual consumption of coal per ton of iron would be smaller when the coke was made in an oven than when the operation was performed in the furnace itself, because in the former case the gases themselves furnish the necessary heat, while in the latter a certain quantity of the coke itself has to be burnt for the purpose. Unfortunately it is difficult to get rid of the gaseous constituents of the coal in coke ovens without at the same time losing a portion of the solid carbon also; nor is this to be wondered at, when the nature of the ordinary coke ovens is

considered. In these the coal is exposed to a very high temperature for periods varying from 72 to 96 hours; and although air is professedly admitted in such a way as to consume the gases only and not the coke, practically this is found to be impossible; and accordingly from a coal containing 70 per cent. of fixed carbon 62 per cent. is about all the coke that is produced.

Different attempts have been made to avoid this waste of carbon in coking; and of most of these plans a trial has been made at the writer's works. In the simplest plan, which may be regarded as a palliation rather than a cure of the evil, the gases, instead of being burnt only above the coke itself in the chamber of the oven, as in the ordinary coke ovens, are conducted into flues running under the bottom and round the sides of the oven, as in that known as Breckon and Dixon's coke oven, shown in Figs. 1 to 4, Plate 42. This form of oven is of course more costly than the ordinary one, and, as might be expected, more expensive to maintain in repair; but on the other hand, as the operation of coking is completed in about 48 hours, instead of 72 to 96 hours as in the ordinary ovens, the shortened period of exposure affords a notable diminution in the action of the air on the coke, with a corresponding increase in the yield of coke obtained.

A second form of coke oven is that known as Appolt's, shown in Figs. 5, 6, and 7, Plate 43, which consists of a series of upright rectangular chambers of brickwork C C, generally eighteen in number, each 16 feet high, $4 \times 1\frac{1}{2}$ ft. at the lower end, and $3\frac{1}{2} \times 1$ ft. at the upper. These chambers or retorts are surrounded by flues, in which the gaseous hydrocarbons are burnt; and the resulting heat being transmitted through the sides of the chambers converts the coal into coke. By following a regular order of charging, sufficient heat is always maintained in the block of ovens for effecting the process of coking as soon as a fresh charge of coal is introduced. In this coke oven 24 hours are sufficient for the completion of the coking in any one of the chambers; and the bottom plate D being then removed, the charge falls out by its own weight and is cooled with great expedition, and loss of coke is avoided by rapid cooling.

A third description of coke oven is the Knab or Pernolet oven, shown in Figs. 8 to 11, Plate 44, in which, as in the preceding one, no combustion takes place in its interior, the gases being burnt in flues running under the bottom and along the sides. Instead however of the combustion being direct, as in the Appolt oven, the gases are conducted through a long pipe to a series of condensers, where the tar and ammoniacal liquors are collected; and the gas freed from these is then used as the source of heat for coking the coal.

In the last two forms of oven it will be observed that the coal is coked in what is virtually a close retort; and hence from these ovens a yield is obtained equal to the entire quantity of fixed carbon contained in the coal. There is little doubt that, even after adding the extra cost of construction, wear and tear, and greater amount of labour in carrying on the operation of coking in these two ovens, the increase in the yield of coke considered as so much combustible matter offers sufficient inducement to have recourse to these more perfect forms of oven; and although the writer's experience with the tar and ammonia condensation connected with the Pernolet oven was not altogether satisfactory, the results obtained in France, where the process was first established, are such as would have encouraged the continuance of the plan in this country, instead of returning, as has always hitherto been the case, to the old simple form of oven entailing extra waste. As regards the quality of the coke produced however, notwithstanding the difficulty of making an accurate comparison between two different kinds of fuel employed in blast furnaces, the writer's experience as well as that obtained at other works is largely in favour of coke made in the ordinary ovens without flues; and as nearly as he has been able to estimate the difference, it is equivalent to something like the extra yield of coke obtained from the three forms of flued coke ovens just described.

The actual quantity of heat evolved by the combustion of different forms of carbon, each combining with the same quantity of oxygen, is stated to have been found by experiment to vary; and

if this be the fact, the consideration naturally arises whether the palpable difference in mechanical condition which is observed in the three varieties of coke made in the flued ovens above described may not affect their calorific powers, as compared with the coke made in the ordinary ovens without flues. The research involved in such an enquiry was however too delicate, tedious, and uncertain, for the writer to be induced to attempt ascertaining any difference which may arise from this cause; and moreover experiment and observation have led him to assign to another cause the inferiority of heating power in the coke made in flued ovens. It will therefore be assumed that 1 cwt. of coke burnt into carbonic oxide at the tuyeres of a blast furnace, with blast at 850° to 900° Fahr. (450° to 480° C.), evolves in all cases about 5400 Fahr.-cwt.-units of heat (3000 C. units), whatever be its mechanical condition; and it is to its mechanical condition that the writer now desires to direct attention.

It is true that the low estimation in which "black ends" and other varieties of soft and imperfectly burnt coke are held by practical smelters, as the result of long observation, might justify the opinion that weight for weight they were endowed with less heating power than the hard silvery-looking fuel so much prized by furnace managers. It appears very probable that the presence of a larger proportion of such black and soft coke is the cause of the inferiority that has been observed in the employment of coke manufactured by heat transmitted through walls of firebrick. Prior to experience indeed it might have been imagined that, when, besides burning the gases inside the chamber in which the coal is coked, the products of combustion were also conducted through flues under and around the oven, the additional heating action thus obtained would have the effect of producing a coke distinguished for its hardness; experience however proves that this is not the fact. It would appear that the process of coking commences from both the top and the bottom of the mass of coal in the oven; and between the two is found a layer of friable coke, possessing the inferior quality which distinguishes coke when imperfectly manufactured. On the assumption already made that coked coal, whether hard or soft, developes the same amount of heat by its combustion, then, provided that the proportion

of soft coke used in a blast furnace is not so great as to cause it to be crushed down and thereby to interfere with the driving of the furnace, its presence ought to be immaterial in a heat-producing point of view. Such it is submitted would really be the case in a furnace employed solely in fusing the pig iron and slag, from which the carbonic oxide generated at the tuyeres would escape as carbonic oxide from the throat, meeting as it would then do with no oxygen during its ascent. Under these circumstances the whole of the coke charged into a close-topped furnace would arrive at the tuyeres and be burnt there. Instead however of all the carbon which enters a furnace leaving it as carbonic oxide, a considerable quantity—rather more than one fourth—leaves it as carbonic acid. Now when carbonic acid meets with carbon at a high temperature, it becomes converted into carbonic oxide, by burning, as it were, the carbon exposed to its influence; but the writer has also established it as a fact that carbon as it exists in hard coke is much less susceptible to this action of carbonic acid than when in the form of soft coke. Consequently the hard coke will have the advantage that a larger proportion of the carbon will leave the furnace in the form of carbonic acid, each 1 cwt. of carbon contained in the carbonic acid having developed by its combustion in the furnace 17,300 Fahr.-cwt.-units of heat (9600 C. units), including the heat in the blast, in comparison with the 5400 Fahr.-cwt.-units (3000 C. units) developed by the combustion of 1 cwt. of carbon into carbonic oxide only.

The sources of carbonic acid in a blast furnace are two, namely the reducing action of the carbonic oxide upon the oxide of iron, and the calcination of the flux. Now there are good reasons for stating that the chief portion of the carbonic acid generated by the reduction of the ore is produced before the temperature of the materials has arrived at that point when carbonic acid acts on carbon in its hard and more compact form. Hence so far as the carbonic acid from the ore is concerned, the hard coke may possibly suffer no diminution in quantity during its passage down the furnace. But if, instead of being uniformly dense, the furnace coke consisted partly or wholly of the softer description, upon which the carbonic acid produced by the ore could act at the same temperature that attends

the reduction of the ore, then more or less of this friable carbon would be dissolved and carried off as carbonic oxide; so that something short of the necessary quantity would arrive at the tuyeres, where its presence is needed to afford the requisite heat for performing the work of that part of the furnace. This deficiency is then necessarily made up by the use of as much more coke as may be found to be carried off in this way.

In the Cleveland district it is of more interest to consider the circumstances which affect the use of coke in the blast furnace, than those which permit the employment of the fuel in its raw state as coal. This arises from the fact that the produce of the Durham coalfield is so bituminous and so apt to fuse on exposure to heat, that in the raw state it offers insurmountable difficulty by impeding the free passage of the blast and thus preventing the regular descent of the contents of the furnace. Where this caking property is absent or less marked than in the case of the Durham coal, there is no doubt an advantage in using raw coal; for it is immaterial whether the loss of a portion of the fixed carbon takes place in the furnace or in the coke oven, and under any circumstances the labour and other expenses connected with coking are avoided when the fuel goes direct from the mine into the furnace. A blast furnace has recently been constructed by Mr. Ferrie at the Monkland Works near Glasgow, so arranged that the coal is coked not by heat evolved in the combustion of fixed carbon at the tuyeres, but by heating it by the combustion of the waste gas in chambers resembling in principle those of the Appolt coke oven. This plan not only saves fuel by applying what in the ordinary furnaces is waste heat, namely the gases which in Scotland are burnt at the tunnel head; but the rapid coking of the coal, it may be, renders the coke both hard and open, and thus removes what has hitherto been considered the chief impediment to the adoption of those tall furnaces which have found such great favour in the Middlesbrough district,—namely the impossibility of driving the blast through so high a column of materials, containing coal in a greater or less state of agglomeration.

Thus far the blast furnace has been regarded as engaged in merely melting the iron and slag, for which a certain quantity of heat is required. For making foundry iron, this heat may in round numbers be considered as that resulting from the combustion into carbonic oxide of 20 cwts. of coke of average quality per ton of iron made, burnt with air heated to 850° or 900° Fahr. (450° or 480° C.); and whatever be the loss of fuel in the upper part of the furnace, which may be taken at $1\frac{1}{2}$ to 2 cwts. of coke, this quantity of 20 cwts. is required for combustion at the tuyeres. The carbonic oxide produced by the oxygen in the blast acting upon the coke may be regarded as exclusively effecting, directly or indirectly, the reduction of the ore, and also supplying the carbon found in the pig iron. What has now to be considered is whether there would be any advantage in relieving the blast furnace of this portion of its work, by previously deoxidising the ore and then introducing it into the furnace in an already deoxidised state. The process of reduction requires for its accomplishment the reducing agent aided by heat. The reducing agent is carbonic oxide, and this may be regarded as a waste product from the melting process, which if not so utilised would be lost so far as the furnace itself is concerned. The heat required for reduction is that evolved by the oxidising of the reducing agent itself, that is, by the conversion of carbonic oxide into carbonic acid; and the heat thus evolved amounts to about 40 per cent. of the total quantity of heat generated in the furnace.

To obtain the iron in its metallic form, it has been proposed to subject the ironstone to the action of the same carbonic oxide gas in a separate apparatus. As regards the work performed in the furnace alone, the use of reduced iron would avoid entirely the generation of carbonic acid by the deoxidation of the ore; and consequently the evil resulting from the subsequent action of the carbonic acid on the coke would be entirely obviated. But it happens fortunately for the process that in the most approved furnaces the reduction of the ore is completed before the materials have acquired the temperature at which carbonic acid is capable of dissolving carbon as it exists in well manufactured coke. The correctness of this view is proved by the circumstance that the

quantity of carbonic acid which escapes from the large furnaces using hard coke corresponds almost exactly with that due to the oxidation of so much carbonic oxide by the oxygen in the ore. It has already been stated that the heat required for the process of reducing an ore of iron is obtained from the further oxidation of the carbonic oxide which serves as the reducing agent; the quantity of heat evolved however by this secondary combustion of carbon from carbonic oxide into carbonic acid is more than is absorbed by the peroxide of iron in parting with its oxygen; and this surplus of heat being generated near the throat of the furnace passes off with the escaping gases. By using therefore in the blast furnace ore which has been previously reduced, it may be possible to avoid a portion of the loss of heat from this source, by avoiding its generation in the upper zone of the furnace where its interception is impracticable.

In order to reduce the ore before it enters the furnace, it has been proposed to expose it to the action of gases brought down from the furnace top, which not having been engaged in the process of deoxidation may be assumed to be free from carbonic acid and therefore suitable for their intended purpose; but it will be seen that all the disadvantages attending the process of reduction as carried on in the furnace itself will still be encountered in the proposed plan. In the furnace the heat communicated by the escaping gases warms up the ironstone to such a temperature that the reducing action once started is continued by the oxidation of the carbonic oxide. To obtain the required elevation of temperature for effecting first the calcination and then the deoxidation of the ore, it is intended to heat up by combustion of furnace gas an apparatus resembling a regenerative hot-blast stove, and then to pass through this stove another portion of gas, which will thus be heated sufficiently for enabling it to effect the reduction of the ore. But in the writer's opinion the gas required to be burnt for this purpose will exceed in quantity that represented by the heat lost at present in the escaping gases; and in addition there will still be precisely the same loss by escape of waste heat as in the furnace itself, inasmuch as the process is in all respects identical. There

will also be the further trouble and inconvenience of having to exclude the atmosphere while the reduced ore is allowed to cool, otherwise it would become oxidised again on exposure to the air in its heated state; and moreover the cooling itself signifies waste of fuel.

In the best constructed furnaces the heat evolved is derived from the several sources in the following proportions, as shown by the writer on a previous occasion:—

1. Combustion of carbon into carbonic oxide at the tuyeres	48 per cent.
2. Introduced by blast	13 ,,
3. Conversion of carbonic oxide into carbonic acid during reduction of ore	39 ,,
	100

If it is attempted when smelting Cleveland ironstone to exceed 13 per cent. as the heat introduced by the blast, the result is simply to diminish by so much the quantity of carbonic oxide that becomes converted into carbonic acid, and the proportions of the heat will then be somewhat as follows:—

1. Combustion of carbon into carbonic oxide at the tuyeres	48 per cent.
2. Introduced by blast (instead of 13 per cent.) .	16 ,,
3. Conversion of carbonic oxide into carbonic acid during reduction of ore	36 ,,
	100

It will here be seen that the third item has lost exactly what the second has gained, leaving the first, which represents the coke heat, unchanged. This does not imply that the same quantity of carbonic acid has not been produced in the two cases by reduction of the ore and dissociation* of some of the carbonic oxide; but the introduction of so much extra heat with the blast (16 instead of 13 per cent.) has

* The "dissociation" of carbonic oxide is the splitting up of this gas into carbon and carbonic acid ($2CO = C + CO_2$). By this action the writer believes the ore during its reduction becomes impregnated with a large quantity of finely divided carbon, which he considers an agent of much importance in the operation of the blast furnace.

enabled the coke to reduce a greater portion of the carbonic acid to carbonic oxide, just as happened with the soft coke at a lower temperature. If however there were no carbonic acid present in the furnace, there would exist no reason why this substitution of blast heat for coke heat might not be made. Practically it may be taken that 1300° to 1400° Fahr. is about as high a temperature of blast as can be maintained by the regenerative stoves; and the difference between working with blast at this temperature and at that usually obtained in cast-iron stoves, say 900° Fahr., would be something under $1\frac{1}{2}$ cwt. of coke saved per ton of iron made. If it were possible to heat the blast still higher than 1400°, this saving of $1\frac{1}{2}$ cwt. would thereby be increased, always supposing no carbonic acid were present. Dealing with the question however according to present experience, the additional cost of any preliminary deoxidation of the ironstone would appear to be too great to render its adoption advisable, inasmuch as the margin of saving that could be effected by avoiding the presence of carbonic acid in the furnace is comprised within the value of $1\frac{1}{2}$ cwt. of coke per ton of iron when the blast is heated to about 1400°.

The second modification of the present plan of treating the ironstone is the direct opposite of that just described, inasmuch as, instead of carrying the process beyond the stage now effected in the calcining kilns, it is intended to charge the ore into the blast furnace in the raw state, as it comes from the mines. Two arguments have been used in connection with this proposal, one in favour of its adoption and the other against it, neither of which however can be maintained. It was urged on the one hand that, as one of the operations of the blast furnace was to remove oxygen, the less duty it had to do in this respect the better; while on the other hand it was apprehended that the addition of so much more carbonic acid to the furnace gases as would be given off from the raw ore would either render them incombustible or greatly reduce their calorific power. Now the separation of oxygen from an ore of iron, though in the abstract a source of heat absorption, is in reality attended with an effective production of heat; because the formation of

carbonic acid, by the oxygen in the ore combining with the carbonic oxide which acts as the reducing agent, develops a greater amount of heat than is absorbed in decomposing the combination of iron and oxygen in the ore. And although the metal in the Cleveland ironstone is in the form of carbonate of the protoxide, the very act of expelling the carbonic acid, whether this be done in the furnace itself or by a preliminary process of calcination, increases the amount of oxygen combined with the iron, at the expense of a considerable quantity of the previously combined carbonic acid. Consequently when the ore is charged raw into the furnace, instead of having to deal with iron in a low state of oxidation, together with a large quantity of liberated carbonic acid gas, the protoxide of iron passes into a higher state of oxidation, and the carbonic acid gas is partially reduced to carbonic oxide. Little or no difference accordingly takes place in the behaviour of the ironstone at the time of reduction, whether it be employed raw or calcined.

The expulsion of the associated water and carbonic acid however are distinct sources of heat absorption; and the writer's experience with the best calcining kilns, such as that shown in Plate 45, proves that the heat thus absorbed does not exceed what is given out by the combustion of 2 cwts. of coke for $3\frac{1}{4}$ tons of ironstone, or for each ton of iron made. If then, as regards the reduction of the iron, no difference attends the substitution of raw for calcined ironstone, the question arises as to what means the blast furnace possesses of discharging the additional duty represented by about 2 cwts. of coke per ton of iron, in the expulsion of the carbonic acid and water from the ironstone, when the ore is used raw.

The appropriation of the heat evolved in the blast furnace has formed the subject of extensive study, and almost the whole amount of heat contributed by the combustion of the coke and by the temperature of the blast may now be said to be accounted for. It may be classified under two different heads, namely that which is expended upon the work proper to the smelting process, and that which is lost; and in round numbers the appropriation of the heat per ton of iron made may be given as follows in cwt.-units:—

WORK DONE.		Cwt.-units Fahrenheit.		Cwt.-units Centigrade.
1. Evaporation of water in coke . . .		500		300
2. Reduction of iron from peroxide . . .		59,400		33,000
3. Impregnation of pig iron with carbon . .		2,700		1,500
4. Expulsion of carbonic acid from limestone .		9,000		5,000
5. Reduction of carbonic acid to carbonic oxide		9,500		5,300
6. Decomposition of moisture in blast . .		4,900		2,700
7. Reduction of silica, phosphoric acid, &c. .		7,600		4,200
8. Fusion of pig iron		11,900		6,600
9. Fusion of slag		30,200		16,800
		135,700		75,400
LOSS.				
10. Transmission through furnace walls, carried off by tuyere water, &c. .	16,600		9,200	
11. Carried off by escaping gases . .	15,800	32,400	8,800	18,000
Total cwt.-units of heat appropriated in furnace		168,100		93,400

Of these eleven items there is but one which in the writer's opinion can be made available for performing in the blast furnace itself the work at present done in the calcining kiln; and that is the heat carried off in the escaping gases, namely 15,800 units, which represents the combustion of from 2 to 3 cwts. of coke in the blast furnace per ton of iron made. If therefore by using raw ironstone the temperature of the escaping gases could be reduced to that of the atmosphere, the waste heat thus saved would be more than sufficient for effecting the process of calcination in the furnace itself, without any increase in consumption of fuel.

There are however practical reasons which appear to the writer to preclude the realisation of such a result. In the first place the fact that the evolution of heat by the generation of carbonic acid takes place near the top of the furnace, and amounts to something like 40 per cent. of the whole heat generated in its interior, would in the writer's opinion always prevent the interception of the 15,800 units now carried away in the escaping gases from even the largest Cleveland blast furnaces. And in the next place, even where the use of raw ironstone has been persevered in, the proportion of

the raw ore has not exceeded one third of the whole ; that is, out of each ton of iron produced, about 6 cwts. were derived from uncalcined ore, while at the same time the whole of the flux was calcined. Many years ago the writer made this question the subject of direct experiment in furnaces of 48 feet height ; and two or three years ago he repeated the trial in those of 80 feet height. The conclusion arrived at, when employing the whole of the ironstone in its raw state, was that the process was the reverse of economical ; for it appeared that, as nearly as could be estimated, each cwt. of small coal saved in the calcining kiln was accompanied by an extra consumption of the same weight of coke in the blast furnace. In two furnaces at present producing one third of their iron from raw ore the temperature of the escaping gases has been ascertained by the writer by means of the electric pyrometer of Mr. Siemens ; and during two hours the temperature of the gas from one of the furnaces was 608° Fahr., and from the other 516°, the average being thus something like 100° lower than the temperature of the gas from a furnace using all calcined ore and raw limestone. This reduction in the temperature is equivalent to 2,700 Fahr.-cwt.-units (1500 C. units), or a saving of about $\frac{1}{2}$ cwt. of coke per ton of iron made; and as the limestone had been deprived of its carbonic acid by calcination, it may be considered that the limit has here been reached of the saving effected by the use of raw ore to the greatest extent hitherto practised.

The presence of more or less sulphur in the Cleveland ironstone may possibly constitute a disadvantage, the writer believes, in connection with the use of raw ore, particularly in making foundry iron. For although, when bisulphide of iron—the form in which the sulphur occurs—is calcined in contact with an excess of atmospheric air, the sulphur can be wholly expelled from the iron, yet when the operation is performed in close vessels, and probably also when done in an atmosphere of carbonic oxide, only one half of the sulphur is got rid of. If therefore this partial elimination of the sulphur is what happens in a blast furnace using the raw ore, the result will be that half the sulphur contained in the ore will reach the hearth, where its presence will be detrimental to the quality of iron made.

The entire expulsion of the sulphur, even when the calcination is effected in an ordinary kiln with an excess of air, is considered however to be somewhat doubtful: not in consequence of there being any difficulty in decomposing the bisulphide of iron, but because, as previously stated, it is not improbable that a portion of the sulphurous acid so generated may be absorbed by the lime always present in the Cleveland ore.

As regards the advantage to be derived from using the limestone in its calcined state instead of raw, it appears from the foregoing table of heat appropriation that 9000 Fahr.-cwt.-units of heat (5000 C. units) are absorbed in expelling the carbonic acid from the raw limestone, and 9500 Fahr.-cwt.-units (5300 C. units) are taken up by the reduction to carbonic oxide of the carbonic acid so liberated. These two amounts are together equivalent to at least 3 cwts. of coke per ton of iron made; but it is well known that the use of calcined limestone is never attended with any such saving of fuel, and this fact the writer believes may be accounted for by the following consideration. In the upper region of a blast furnace there is a space where carbonic acid up to a certain proportion, say 40 volumes of carbonic acid to 100 of carbonic oxide, does no harm, because neither is the temperature in that region high enough for enabling it to take up carbon from the coke in the presence of so large an excess of carbonic oxide, nor is there any metallic iron present in that part of the furnace which the carbonic acid could oxidise. Now when the limestone is used raw, its carbonic acid is not driven off in this region, because the heat is not intense enough to expel it; and consequently the limestone does not part with its carbonic acid until it descends to a lower point in the furnace, where the heat is greater. The temperature however that is sufficient for expelling the carbonic acid from the limestone is also high enough to effect its reduction to carbonic oxide by the incandescent carbon there present; and thus in addition to the 9000 units of heat absorbed in expelling the carbonic acid, 9500 units are at the same time further absorbed in the reduction of the carbonic acid so liberated. Were there no other circumstance to interfere, it might

be anticipated that the previous removal of the carbonic acid from the limestone, by preliminary calcination outside the blast furnace, would effect the saving of both the amounts of heat thus absorbed in the furnace by the use of raw limestone; but it does not do this, for the simple reason, the writer believes, that caustic lime absorbs carbonic acid with great rapidity at a moderate temperature. When therefore calcined limestone is charged into the blast furnace, the carbonic acid present in the upper part of the furnace, which is harmless in other respects, is taken up by the limestone to the extent of pretty nearly the original quantity contained in the limestone before calcination; and this carbonic acid is carried down by the limestone to the lower zone in the furnace, where its expulsion and reduction to carbonic oxide are effected in the same way as in the case of using raw limestone. The absorption of carbonic acid by the calcined limestone in the upper part of the furnace is of course attended with the development of exactly the same amount of heat that is afterwards absorbed in the expulsion of the same quantity of carbonic acid from the limestone in the lower part of the furnace; and these two amounts accordingly neutralise each other.

The use of calcined limestone consequently requires the combustion of a sufficient quantity of small coal outside the blast furnace to drive off the carbonic acid from the limestone; and also the combustion of a sufficient quantity of coke inside the furnace for reducing to carbonic oxide the rather smaller quantity of carbonic acid which has subsequently been taken up again in the furnace by the calcined limestone. On the other hand, the use of raw limestone requires the combustion of a sufficient quantity of coke inside the furnace, both to drive off the carbonic acid from the limestone and to reduce it to carbonic oxide. It follows therefore that all the advantage to be derived from previous calcination of the limestone is that which results from expelling the carbonic acid by the combustion of small coal in the calcining kiln, instead of by the consumption of coke in the furnace itself; and the difference in the value of the fuel employed offers a certain margin of economy in expense, although none in heat.

The general conclusion arrived at therefore, with regard to the preliminary treatment of the blast-furnace materials in the Cleveland district, is that there is little economy of fuel to be hoped for, either by employing on the one hand raw coal instead of coke, or by using the ironstone raw instead of calcined, or on the other hand by using the limestone calcined instead of raw: always supposing that the blast furnace engaged in the work is one of the present ordinary Cleveland furnaces.

Mr. C. W. SIEMENS thought that in the paper just read the subject of the preliminary processes for the preparation of the blast-furnace materials was treated in a most exhaustive manner, the theoretical reasoning being based upon extensive practical experience; and valuable data were furnished for practical metallurgists. With regard to the question of the advantage to be gained by coking the coal previous to using it in the furnace, it had been urged that, when raw coal was charged into the furnace, a portion of the furnace heat had to be expended in coking the coal within the furnace, by driving off the volatile constituents, which were then simply expelled and wasted as far as the blast furnace was concerned, not being utilised for any generation of heat; whereas when the coking was done beforehand in coke ovens, the gaseous constituents driven off were utilised in the recent improved ovens, by being conducted through flues surrounding the ovens, where their combustion supplied heat enough for accomplishing the coking of the coal in the ovens. Notwithstanding this view of the case however, the common form of coke ovens appeared to be preferred by the writer of the paper, although no use was made in them of the gases driven off, and they thus failed to realise the main advantage on the ground of which the preliminary coking of the coal was recommended. He was not able however to concur in considering

the common coke ovens preferable to the more refined plans which had been described for burning the gases driven off; and at some new blast furnaces near Swansea he was now erecting a set of coke ovens similar in construction to that described in the paper as Appolt's. This form of oven was extensively used in France with considerable success; but the result obtained with it was not always uniform as regarded the hardness of the coke produced, which was not so hard as the best Durham coke. This seemed to him to be in consequence of a want of heat in the oven towards the end of the coking process. At the beginning of the operation there was plenty of gas to maintain the required heat for coking the coal; but afterwards, as the fuel approached more and more nearly to the state of pure carbon, less and less gas was evolved and the heat consequently fell off. To obviate this objection he had introduced a modification in the construction of the ovens, so as to admit of applying a regenerator to each block of ovens; the surplus gas given off at the beginning of the coking was made use of for heating up the regenerator, through which a current of air was afterwards passed, so as to take up the heat again and convey it back to the ovens for completing the coking, thus maintaining the required heat to the end of the process. By this arrangement he believed a perfect command would be obtained over the heat of the ovens, and a very hard coke would be produced.

Another object aimed at in the adoption of this plan was to use a large proportion of anthracite coal in the coke ovens, that being the purest description of coal met with in South Wales, and containing so little gas that it might be looked upon as a natural coke. In the ordinary coke ovens, or in the Appolt ovens as hitherto employed, it would not be possible to coke coal of that description successfully, because the heat obtained for carrying on the process would be still less than in coking the coals ordinarily used, and the coke would be of too brittle a character. But by the application of a regenerator in connection with the Appolt ovens, so as to economise the gases given off and get a greater heating effect, he had reason to believe that coke of a great degree of hardness would be obtained, from a mixture of coal containing a large

proportion of anthracite. If it should prove to be the case that the gases contained in the anthracite could by this means be entirely removed and also fully utilised, then there could be no doubt that it would be an advantage to coke all the anthracite supplied to the South Wales blast furnaces, instead of using the raw coal as at present. He concurred in the opinion expressed in favour of employing very hard coke in the blast furnace, in order to prevent its destructive distillation near the top of the furnace by the carbonic acid present in that region.

In reference to the question of the preparation of the ore—whether it was to be fully oxidised into peroxide, or whether it should rather be reduced to metallic iron before being charged into the blast furnace—this was a difficult subject, and he thought there was much to be said in favour of each plan. If however, as he believed, decided economy would result from concentrating all the operations of smelting as much as possible within the furnace itself, it would be best to supply the ore raw instead of calcined, and to perform both its calcination and its reduction within the furnace. This would prevent loss of heat by cooling of the calcined ore before it was charged into the furnace.

Mr. C. Cochrane remarked that the complete deoxidation of the ironstone previous to its introduction into the blast furnace was a project which he had contemplated some time ago; and it was correctly mentioned in the paper now read, that if this could be accomplished it would leave the blast furnace nothing to do beyond the melting of the iron and slag. He was not prepared at present to go further into the question of the practicability of such a process; but he did not think it could be looked upon as identical with the ordinary process which took place in the reduction of the ore within the blast furnace. For if a portion of the waste carbonic oxide escaping at the furnace throat were burnt with atmospheric air in a regenerative apparatus for heating the materials prior to their entrance into a reducing chamber, in which the ore was then deoxidised by the remainder of the waste carbonic oxide, there would be a great difference between this process and that taking place inside a blast furnace, inasmuch as it would be impossible to

introduce in the blast furnace the air requisite for burning a portion of the carbonic oxide in the same manner as in the regenerative portion of the reducing apparatus.

Mr. Wilson Lloyd observed that, with regard to the alleged absence of any gain in using raw coal in the blast furnace, on the ground that the furnace was thereby converted to a certain extent into a gas retort while the coal was being coked, it must be borne in mind that on the other hand in coking the coal in ovens a large amount of heat was lost, because the coke after drawing the ovens was allowed to cool, and was very frequently cooled with water, some of which would be retained in it and would have to be evaporated in the blast furnace, whereby heat would be absorbed. Also in reference to the desirability of using very hard fuel in the blast furnace, he presumed the remarks upon this point were intended to apply particularly to the Cleveland furnaces, which were large in size; because the nature of the fuel that could be advantageously used would depend greatly upon the height of the furnaces. In the South Staffordshire furnaces, where the height was so much less than in the Cleveland district, an extremely hard fuel would be useless; for in an attempt which he had made to use anthracite coal in a small furnace, he had found that some portion of the coal came through the furnace unconsumed, and the results were unsatisfactory. But for tender coal on the other hand a small furnace was desirable.

Mr. Bell said the opinion he had expressed in favour of the ordinary coke ovens without flues had only been arrived at after a long and careful trial of the different forms of flued ovens described in the paper, none of which had he been able to consider practically successful in coking the Durham coal for the use of the blast furnace. The want of success however was not due to any deficiency of heat for completing the coking operation to the end; on the contrary the gas given off from the ovens was not only sufficient for carrying on the coking process to its termination, but there was even surplus enough for firing a steam boiler also. What the effect might be of applying the regenerative system in connection with the Appolt oven, for coking either the South Wales anthracite or the Durham

coal, he was unable to anticipate; and he hoped the experiment about to be made at Swansea might prove more satisfactory and profitable than his own trials had been.

The idea of effecting the deoxidation of the ironstone by a preliminary process conducted outside the blast furnace was one with which his own views were entirely at variance, as he did not understand how any economy could be realised by smelting the ore in two operations, instead of performing the whole process at once within the blast furnace. For in the blast furnace as at present conducted, the generation of carbonic oxide at the tuyeres developed the heat requisite for melting the iron and slag, while the same carbonic oxide was also the reducing agent which effected the deoxidation of the ore. But instead of allowing the reduction to be effected in this way within the furnace, it was proposed to take the waste carbonic oxide at present escaping from the furnace top, and employ it for performing the work of reduction in a separate furnace. Supposing however there were any good to be obtained from that mode of proceeding, he did not see why the second furnace should not be placed upon the top of the first; and the result would then be almost the very arrangement already existing in the shape of the high blast furnaces now in use. It was indeed contemplated to burn the waste carbonic oxide in the preliminary furnace by admitting a supply of atmospheric air for the purpose, which of course could not be done inside the blast furnace; but as the heat to be obtained by the combustion of the gas was the only point to be considered, he did not see how any advantage could result from supplying the requisite oxygen by means of air, instead of deriving it from the ore in the process of deoxidation.

The cooling of the coke on drawing it from the coke ovens occasioned necessarily a certain loss of heat, which would of course be prevented by the use of raw coal in the blast furnace.

Mr. E. F. Jones, referring to the question of using the ironstone calcined or raw in the blast furnace, mentioned that at the Normanby Iron Works, Middlesbrough, they had been using half raw and half calcined ore during the last twelve months in furnaces of 10,000 cubic feet capacity, with a temperature of blast averaging

930° Fahr.; and the consumption of coke per ton of iron made from the raw ore had been as low as in the largest and most economical furnaces in the district, working with the whole of the ore calcined.

Mr. E. Williams enquired whether it had been found that the higher numbers of foundry iron could be made as readily with raw ore as with calcined ore. He had himself made a trial of raw ore to the extent of about 40 per cent. of the entire charge of ironstone, for three or four months at the Cleveland Iron Works of Messrs. Bolckow and Vaughan, Middlesbrough; but though the furnaces worked well the whole time, he had not been able to get the higher numbers of pig iron previously obtained when nothing but calcined ore had been used. Having gone minutely into the matter to ascertain whether there was any economy in the use of raw ore, he had come to the conclusion there was none; but on the contrary there was a slight diminution in the make of the furnaces. The most serious objection to using the ore raw was the inability to produce the higher numbers of iron.

Mr. E. F. Jones said he had not found any difficulty in making grey foundry iron from raw ore, and the average number obtained during eight months' working without any change in the charges of the furnace had been 3·56, the quantity of white iron being less than 2 per cent. The only difference in the grey iron produced was a rather closer appearance of the fracture, and the metal contained more uncombined carbon and less silicon than when made from calcined ore. It also appeared to him that the reduction of the raw ore took place at a somewhat lower temperature. The iron produced had been tested both by analysis, and also practically by being employed in the manufacture of hardware in Birmingham, for which it was found thoroughly suitable.

Mr. E. Williams said his own experience was the same as to the iron being finer in grain when made from the raw ore; and that it had to go for a lower number.

Mr. W. Barrett mentioned that at the Norton Iron Works near Stockton they had for several months past been using one third raw ironstone with two thirds calcined, and the iron produced was rather finer in grain, but equal if not superior in quality to a larger grained

iron made from calcined ore alone. They used 300 tons a week of this iron in the foundry at the Norton Works, and it had proved very good metal.

Mr. C. Cochrane said that at the Ormesby Iron Works, Middlesbrough, they had also tried the use of raw ore to the extent of half raw and half calcined, in a furnace of 20,000 cubic feet capacity; but although the iron made was of good quality for all the purposes for which it was usually employed, at the same time there was a great falling off in the quality of gas from the furnace, coupled with an increased consumption of coke, and it had been necessary to use coal under some of the boilers in consequence of not having gas rich enough. A good deal might depend he thought upon the size of the furnace for working raw ironstone; and there might be some advantage in a narrower furnace, such as that at Normanby of 18 feet diameter and 73 feet height.

Mr. W. Cochrane enquired whether the objection to the Appolt coke oven was the cost of construction and maintenance, or the necessity for using a great quantity of water for cooling the coke when drawn; and also whether the working of this and the other flued ovens had now been discontinued.

Mr. J. Marley enquired whether any difference had been found in the quantity of coke consumed in the blast furnace per ton of iron made, according as the coke had been made in ovens having side and bottom flues, or in the common ovens without such flues but with only top flues and chimneys. When the flued ovens were first introduced, there was a great prejudice against using in the blast furnace the coke so made, particularly in the case of the high furnaces; but he understood the coke made in flued ovens was now gradually coming into use even for high blast furnaces, and at the collieries of one of the largest iron-making works in that neighbourhood sets of coke ovens were now being built with side and bottom flues. Having been engaged for a number of years in the manufacture of coke he should be glad to know what were the comparative results of using in blast furnaces coke made in flued or unflued ovens, as to the quantity of coke required per ton of iron made, the burden of the furnace, and the difference in the quality of the iron, if any.

Mr. Bell observed that, in reference to the success attending the use of raw ore in the blast furnaces at the Normanby Iron Works, he had on previous occasions expressed an opinion that from 12,000 to 15,000 cubic feet was as large a capacity of furnace as was desirable; and he was by no means convinced that even 12,000 cubic feet might not be more than was really wanted, and perhaps 10,000 cubic feet, as at Normanby, might be large enough for advantageous working. Another point of great importance in the manufacture of iron was the care bestowed upon the management of the blast furnaces; and he believed that much of the excellence of the results obtained at the Normanby furnaces might be attributed to the very careful management which they received.

As regarded the statement that the pig iron made from raw ore in the Normanby furnaces had been found by analysis to contain more uncombined carbon than iron made from calcined ore, he did not think the quantity of uncombined carbon afforded any criterion of the richness of the metal, for he had found that the whitest iron might often contain as much uncombined carbon as the richest grey iron; and having collected an extensive series of analyses of iron made in the Cleveland district, he had come to the conclusion that it was impossible from chemical analysis alone to tell which was white iron and which was grey. The same remark applied to the quantity of silicon contained in the iron, which he had found to vary from $\frac{3}{4}$ to $1\frac{1}{2}$ per cent. in different samples of Cleveland iron made under precisely the same circumstances; that is, the proportion of silicon was in some cases only half what it was in others, without there being, as far as he was aware, any known reason for the difference. These were some of the complicated questions at present unsolved in connection with the working of blast furnaces.

The use of raw ore in the furnace was generally decided upon, he supposed, with a view to saving the expense of calcination; but by adopting suitable arrangements he believed the process of calcining the ore might be effected without involving any extra expense beyond the first cost of the calcining kilns. It was only necessary to tip the ironstone direct out of the wagons into the kiln, instead of upon the ground; and along with it a small quantity of

the commonest description of coal had also to be tipped into the kiln, instead of charging probably a corresponding additional quantity of coke into the blast furnace. In the improved calcining kiln shown in the drawing (Plate 45), first erected at the Eston Works near Middlesbrough, the whole process was effected without involving any extra labour beyond that required in working furnaces with raw ore; by simply opening the doors of the hoppers at the bottom of the kiln the calcined ore was run out into the charging barrows and conveyed to the furnace top with no more labour than would be expended in taking the raw ore from the ironstone wagons to the furnace in the same manner; and the only attention required to be given to the working of the kiln was to regulate the quantity of coal tipped in at the top, according to the degree of calcination of the ore drawn out at the bottom, the calcining process within the kiln being then entirely self-supporting. A possible objection to the use of raw ironstone in the blast furnace was that the sulphur contained in the Cleveland ore in the form of bisulphide of iron could not then be got rid of to the extent of more than one half; whereas in the calcining kiln the whole of the sulphur was driven off from the iron. In Germany he had found the complete expulsion of the sulphur was regarded as a point of the greatest importance, and at some of the ironworks making particularly good iron from ores containing sulphur the mere calcination of the ironstone was not considered sufficient, he had been informed, but the calcined ore drawn from the kilns was allowed to lie in the open air for several months, in order that the last particles of sulphate of iron might be washed out by the rain and the ore be thus freed from that contamination before being charged into the blast furnace.

The failure of the different plans of flued coke ovens erected for trial at his own works was owing in a great measure to the heavy cost of construction and maintenance consequent upon their flued structure; but having erected them he had not yet thought it advisable to discontinue working them. In the event however of having to put up any new ovens, the experience of these would lead him to revert to the common construction without flues; and

although it might be thought the unfavourable opinion as to the employment of coke made in flued ovens was less strongly entertained than formerly, the fact remained that coke so made was not yet coming into use for blast-furnace purposes.

Mr. E. Williams believed it was still the general opinion that coke made in flued ovens was not so suitable for the blast furnace as that made in the common ovens without flues. He could confirm what had been said as to the advantage of the improved calcining kiln that had been described, which discharged itself into the barrows by the inclined hoppers at the bottom when the doors were opened. Several of these kilns were now in use at the Cleveland Iron Works, where they were found completely satisfactory in working. The very simple and efficient arrangement for discharging the calcined ore at the bottom without labour was due to Mr. Borrie, the engineer of those works.

The President remarked that the manufacture of pig iron was not only a most interesting and important operation, but also evidently a most occult process, as it appeared that even those who had been longest and most extensively engaged in it still found many points remaining that called for further research. The preliminary treatment of the raw materials, which had so important a bearing upon the operations of the blast furnace, had been very fully gone into in the paper now read; and he had no doubt that great advantage would result to all concerned in the management of blast furnaces from a careful consideration of the views which had been advanced.

He moved a vote of thanks to Mr. Bell for his paper, which was passed.

The following paper, communicated through Mr. James Kitson of Leeds, was then read:—

DESCRIPTION OF THE IMPROVED COMPOUND-CYLINDER BLOWING ENGINES AT THE LACKENBY IRON WORKS, MIDDLESBROUGH.

By Mr. ALFRED C. HILL, of Middlesbrough.

This pair of Blowing Engines was designed for the purpose of working with steam at a pressure as high as 85 lbs. per square inch above the atmosphere; and the principle of compound cylinders with surface condensers was consequently adopted, one engine being high-pressure non-condensing, and the other low-pressure condensing, supplied by the exhaust steam from the high-pressure engine. One reason for the adoption of this principle of engine was that the natural supply of water available at the Lackenby Works is obtained from gypsum strata, and is therefore entirely unsuitable for use in the boilers, on account of the large proportion of lime contained in the water; accordingly if the ordinary high-pressure non-condensing engines had been employed, waterworks water would have had to be used for the boilers, thereby increasing materially the cost of engine power, and consequently entailing an appreciable increase in the cost of making pig iron. Another consideration which rendered it especially desirable that the most economical arrangements should be adopted for using the steam, was that the waste gases from only two blast furnaces were for the present available for heating the steam boilers and also the hot-blast stoves; and from circumstances that do not admit of complete control the supply of gas was thus liable to be often limited in quantity, so much as to cause a difficulty in maintaining steam without burning coals under the boilers, whilst also keeping up the high temperature of blast which is so essential as the principal source of economy of coke in the manufacture of pig iron.

The engines are shown in Plates 46 to 48; Fig. 1 being a side elevation and part section, Fig. 2 a transverse section, and Fig. 3 a plan. The engines are of the vertical direct-acting kind, a class which was first successfully introduced for use as blowing engines in the Cleveland district; and the writer believes these to be the first direct-acting *compound* engines which have been applied to that purpose.

The steam-cylinder A of the high-pressure engine is 32 inches diameter, Fig. 1, and immediately below it is the blowing cylinder B of 80 inches diameter; the piston-rod for both cylinders is in one piece, and is carried through the bottom of the blowing cylinder, and attached to a crosshead gudgeon, from which the connecting-rod is carried to the crank pin. The low-pressure engine is in all respects the same, excepting that the steam cylinder C is 60 inches diameter, instead of 32; this cylinder and its covers are completely steam-jacketted, as are also the sides and ends of the steam-chests. Both the steam cylinders have a steam-chest placed at each end, and the steam passages are as short and direct as possible. Balanced slide-valves are used, made upon Dawes' plan for taking off the pressure by having a moveable back which is connected to the valve by a thin flexible steel plate.

Both engines have a stroke of 54 inches, and they are coupled together with cranks placed directly opposite to each other, instead of as usual at right angles; and the flywheel is relied on for carrying the engines over their centres. This arrangement the writer believes to be novel for blowing engines, and decidedly preferable; for by coupling them in this manner they are as perfectly balanced as the best beam engines, without having to overcome the friction caused by the inertia of the large additional weights of the beams in motion. Another reason for placing the cranks in this position was that the steam might be expanded in both cylinders in the most advantageous manner, by the low-pressure cylinder beginning to take the steam at the same moment that the high-pressure cylinder begins to exhaust. Moreover the position of the cranks opposite each other removes the cause of the breakages which are so common to blowing engines when coupled at right angles and controlled by a heavy flywheel; for in the writer's opinion these breakages arise from the

tendency to sudden acceleration in speed of one engine over the other at the commencement of each stroke, in consequence of the full steam pressure being at that time upon both pistons simultaneously, whilst the resistance of the blast pressure is then acting against only one of the blowing pistons. This evil has no doubt been aggravated by the circumstance of the steam valves having lead given to them, similar to engines that transmit their power through the flywheel shaft, instead of acting directly upon their work as in blowing engines. In the present instance, with the cranks set opposite to each other, the flywheel is only wanted for enabling the cranks to pass the centres, and not for regulating the piston speed, which is controlled by the resistance of the blast pressure; and only a very light flywheel is therefore required. More than one pair of engines in this neighbourhood have broken down from being coupled at right angles; and in one of these cases the pair of engines have been disconnected in consequence of the breakages, and a separate shaft and flywheel has been attached to each engine.

A surface condenser D, Figs. 1 to 3, is used in the Lackenby engines, which is placed upon the bottom bed-plate of the low-pressure engine, with the circulating pump E, the air-pump F, and the feed-pumps G G attached to it on the outer side. These pumps are worked by means of a pair of wrought-iron beams H, which are connected at the inner end to the engine crosshead gudgeon by a pair of links, and at the outer end are attached by links to a crosshead J common to the whole of the pumps. The condenser, shown to a larger scale in Figs. 4 and 5, Plate 48, contains 1008 solid-drawn brass tubes, each 5 ft. 8 ins. long and $\frac{3}{4}$ inch diameter outside, giving a total cooling surface of 1080 square feet. The tube-plates are of brass 1 inch thick, and the ends of the tubes are passed through drilled holes in the tube-plates, and are kept tight by means of cotton cord packing in a stuffing-box, which is secured by a screwed gland, as shown half full size in Figs. 6 and 7; this kind of packing has been well tested and proved to be effectual in marine-engine condensers.

The circulating pump E, Figs. 1 and 3, is 16 inches diameter and 27 inches stroke, and is single-acting; it forces the condensing water first through the tubes which are placed in the bottom half of the condenser, and then through the remainder of the tubes in the upper half. In addition to this pump, means are provided for passing water through the condenser from a water tank placed upon the top of the engine house, so as to be able to obtain a vacuum at starting the engine, or if the circulating pump should from any cause be temporarily deranged in its action. The air-pump F, Fig. 2, is 24 inches diameter and 27 inches stroke, and is attached to the lowest point of the condenser; the condensed water is lifted by it into the hot-well K, Fig. 4, which is placed upon the top of the condenser D; the exhaust steam-pipe is carried through the hot-well on its passage to the condenser, by which means the temperature of the feed-water is slightly increased. The two feed-pumps G G, Fig. 1, are each $3\frac{1}{2}$ inches diameter and the same length of stroke as the circulating and air pumps; they take their supply of water from the hot-well. A $2\frac{1}{4}$ inch injection cock with a copper distributing pipe L, Fig. 4, is fixed in the condenser near the top, immediately under the point where the exhaust steam is admitted; this injection is for making up the extra water supply required for the boilers, as afterwards referred to, and at the same time materially assists in obtaining a good vacuum. The several pumps &c. are of brass, and are fitted up in the same manner as in the best marine engines.

One of the blowing cylinders is shown in section and plan in Figs. 8 and 9, Plate 49. The inlet and outlet valves are shown in Figs. 10 to 15, Plate 50. The inlet valves I I on the bottom of the cylinders, shown in Figs. 12 and 13, are circular disc-valves of leather, and are eighteen in number, as shown in the plans, Figs. 3 and 9. The inlet valves T on the top of the cylinders, shown in Figs. 10 and 11, consist of ten rectangular boxes, having openings in their vertical sides, inside which are hung leather flap-valves; the box covers are made hollow, as shown in Fig. 10, and are carried down inside and between the backs of the leather flaps, so as to reduce the cushion or air space to a minimum. The outlet valves V, shown in Figs. 14 and 15, are ten in number at each end of the

cylinders, and are hung against flat gratings which are fixed round the circumference of the cylinder, as shown in the plan, Fig. 9; enclosing these valves is an air-tight wrought-iron casing M, into which the blast is delivered, and a branch N at one side conveys the blast to the main. The area of the inlet valves is 860 square inches, or about 1-6th the area of the piston; and the area of the outlet valves is about 600 square inches, or nearly 1-8th the area of the piston. The clearance of the piston from the cylinder covers at each end of the stroke is $\frac{3}{4}$ inch. The arrangement of the blowing-cylinder valves has been considered and carried out with particular care, with the object of reducing to a very small amount the cushion or air space between the piston and valves at the ends of the stroke. This amounts to an average of only $4\frac{2}{3}$ cubic feet at each end, or only 3 per cent. of the capacity of the cylinder, instead of the considerably larger proportion that is usual in blowing engines.

In order to obtain with safety the high steam-pressure desired for these engines of 85 lbs. per square inch, it was decided to employ boilers made upon Howard's plan, consisting entirely of tubes with small diameters of surface exposed to pressure and small total contents of water. The principal supply of feed-water for the boilers being the condensed water from the surface condenser, it is probable that if there were no other source of water supply the boilers would be liable to serious corrosion from the extreme softness of the water. But as the steam supply from the boilers has to be sufficient not only for the blowing engines, but also for working the tuyere-water pumps, the furnace-hoist engine, and the steam-ram lift for raising the wagons to the tops of the kilns and hoppers, an additional supply of feed-water has to be provided by admitting some injection water to the condenser; and in this way it is expected that any danger of serious corrosion or of rapid incrustation in the boilers will be prevented.

To provide against any risk of the blowing engines being stopped in the event of accident to the condenser, the engines are both of them arranged to work as non-condensing engines by simply opening

and shutting a few valves, the two cylinders being then disconnected from each other, and each supplied with steam direct from the boiler, while each cylinder has also a direct exhaust into the atmosphere. In order to prevent any risk of overstrain in the large cylinder, the full boiler-pressure is prevented from entering that cylinder, by means of relief valves placed upon the steam chest, which limit the pressure of steam that can exist there. The low-pressure engine can also be worked by itself if required, as a single condensing engine taking its supply of steam direct from the boilers; and either engine can be worked independently by taking off the connecting-rod of the other engine. As the engines are balanced when working compound, and the slide-valves are set permanently for that mode of working, it occurred to the writer that by placing a throttle-valve in the steam pipe at its entrance into the top steam-chest, the admission of steam upon the top side of each piston could be controlled, as the most eligible way of balancing the engines, when working singly instead of combined.

In conclusion, the object aimed at in the arrangement of these engines has been to obtain economy in consumption of fuel by the use of a higher class of engine; but at the same time to ensure freedom from risk of stoppage owing to the introduction of a more complicated construction of engine than has hitherto been usual for this purpose.

Mr. Hill said that the engines were now in course of erection at the Lackenby Iron Works, but as the works were not yet in operation as had been expected, the engines were not yet at work, and he had not been able consequently to obtain indicator diagrams from them for showing their actual working at the present meeting.

The PRESIDENT thought it would be preferable to reserve the discussion of the subject until the engines had been got to work, in order that the results of their working might then be given. He accordingly proposed the adjournment of the discussion; and moved a vote of thanks to Mr. Hill and Mr. Kitson for the paper, which was passed.

The Meeting was then adjourned to the following day. In the afternoon a number of the Blast-Furnace Works, Rolling Mills, and Engineering Works in Middlesbrough and the neighbourhood were visited by the Members.

CLEVELAND IRON DISTRICT.

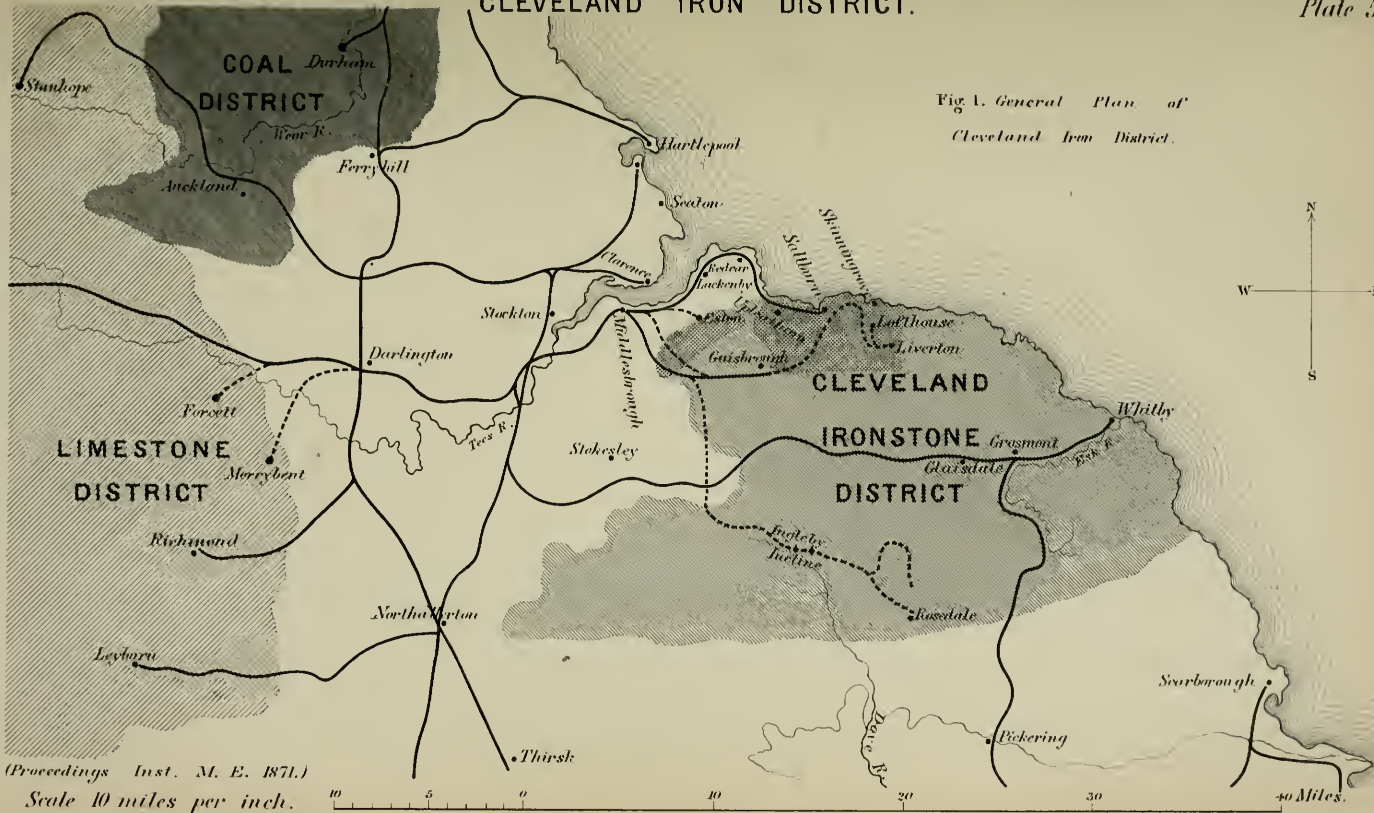


Fig. 1. General Plan of Cleveland Iron District.

(Proceedings Inst. M. E. 1871.)

Scale 10 miles per inch.

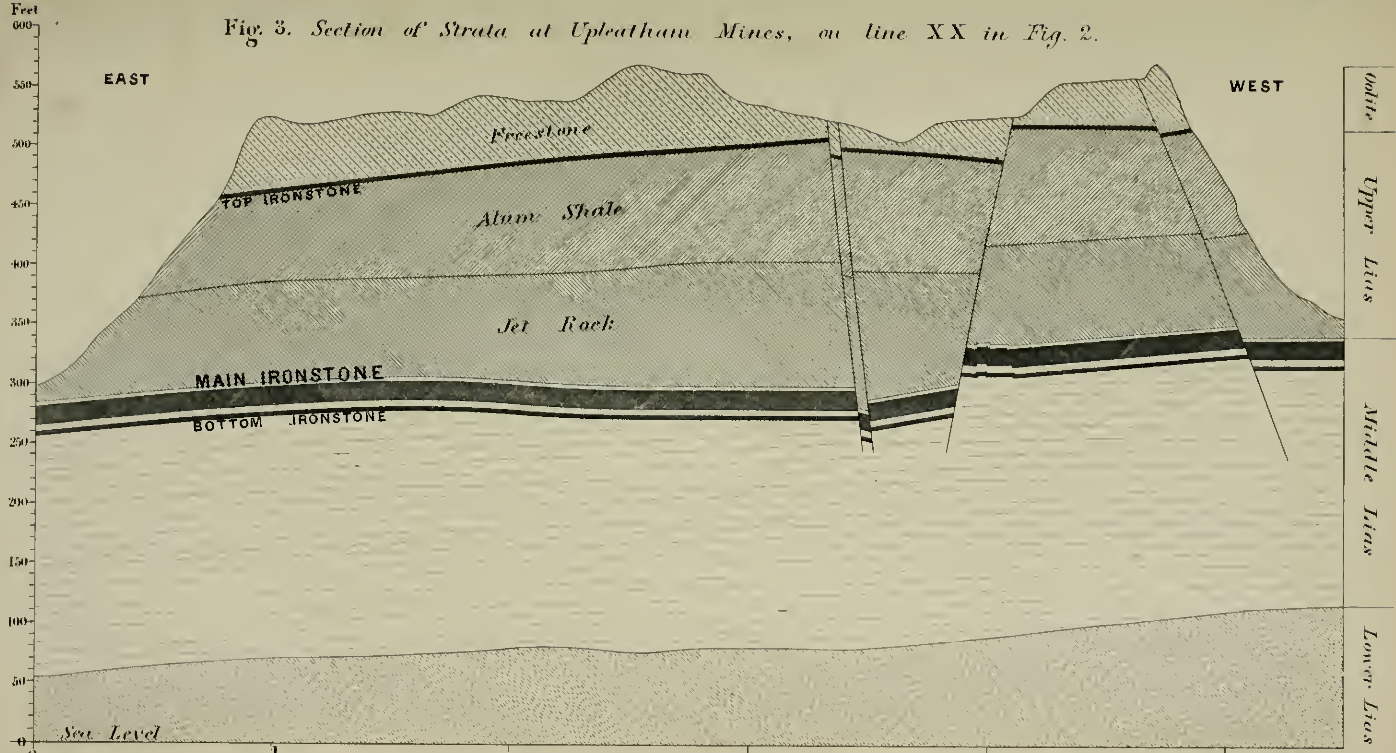
CLEVELAND IRON DISTRICT.

(Proceedings Inst. M. E. 1871.)

Scale 10 miles per inch.

CLEVELAND IRON DISTRICT.

Fig. 3. *Section of Strata at Upleatham Mines, on line XX in Fig. 2.*



(Proceedings Inst. M. E. 1871.)

CLEVELAND IRON DISTRICT. *Plate 54.*

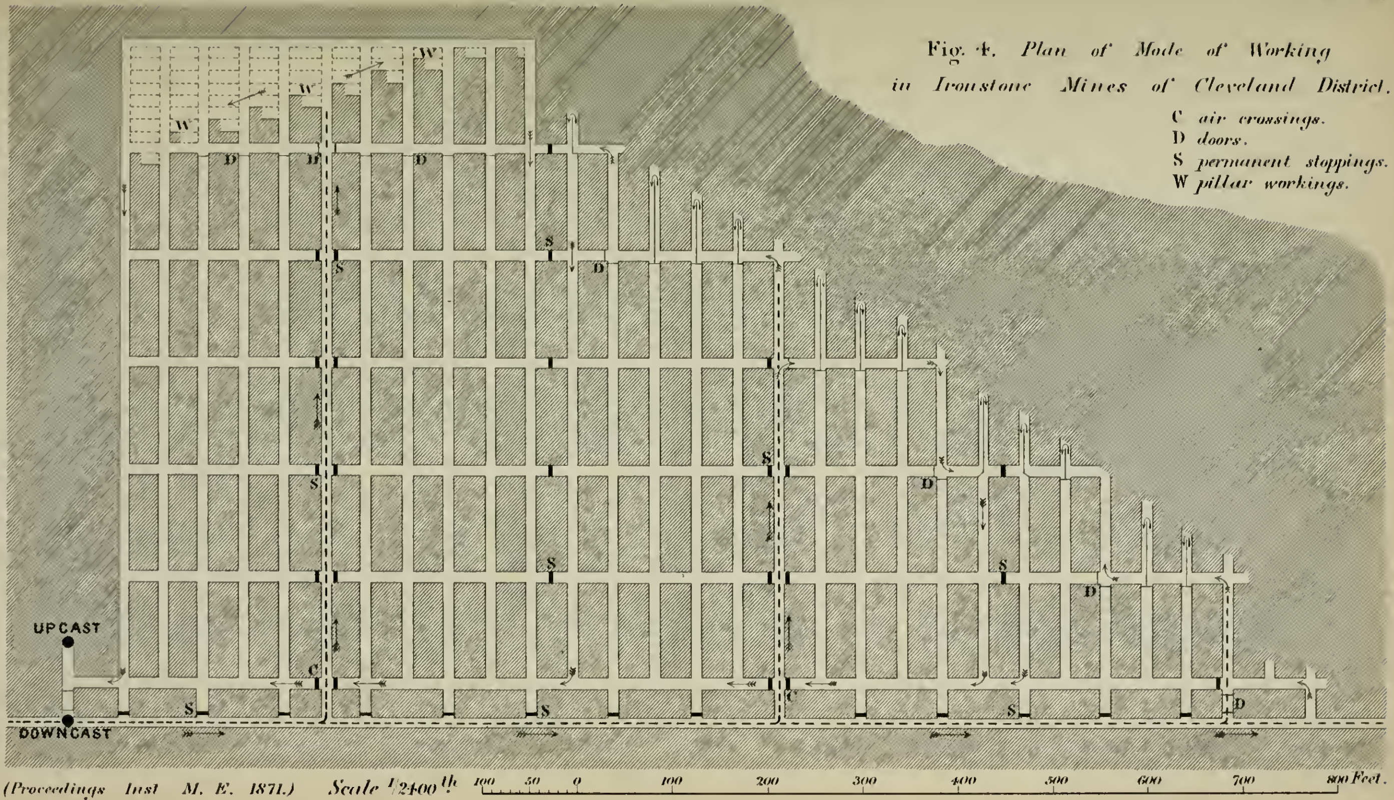


Fig. 4. *Plan of Mode of Working in Ironstone Mines of Cleveland District.*

(Proceedings Inst M. E. 1871.) *Scale 1/2400th*

INGLEBY BREAK DRUMS.

Fig. 1. *Longitudinal Section of Ingleby Incline.*

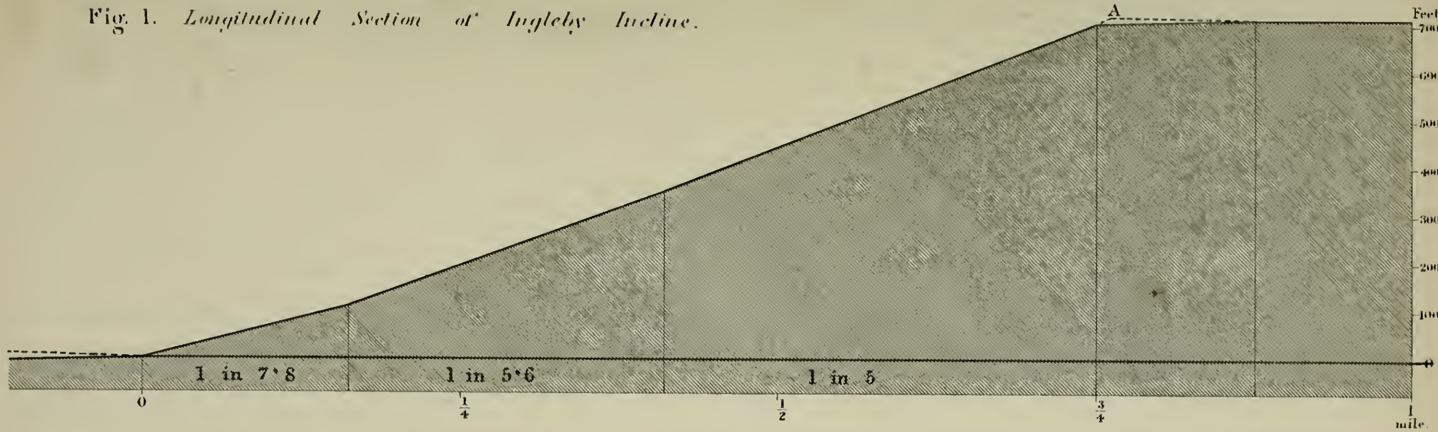
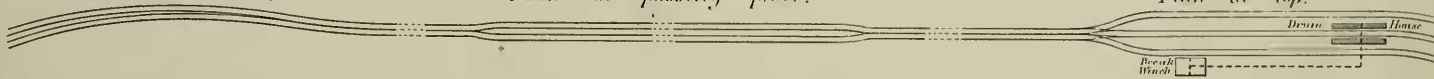


Fig. 2. *Plan of Incline.*

Plan at bottom. *Plan at passing place.* *Plan at top.*



(Proceedings Inst. M. E. 1871.)

INGLEBY BREAK DRUMS.

Fig. 3. *Side Elevation of Drums and Break Gear.*

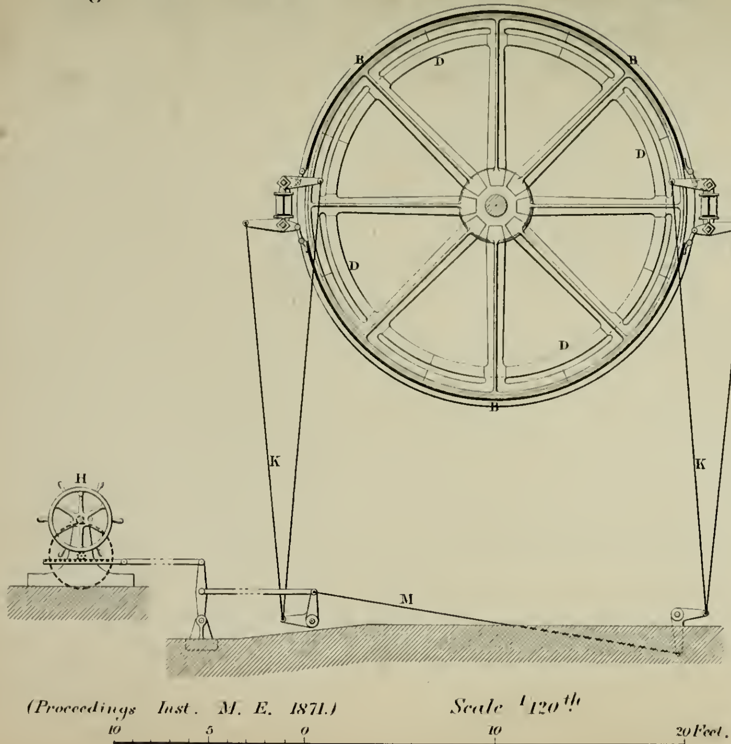
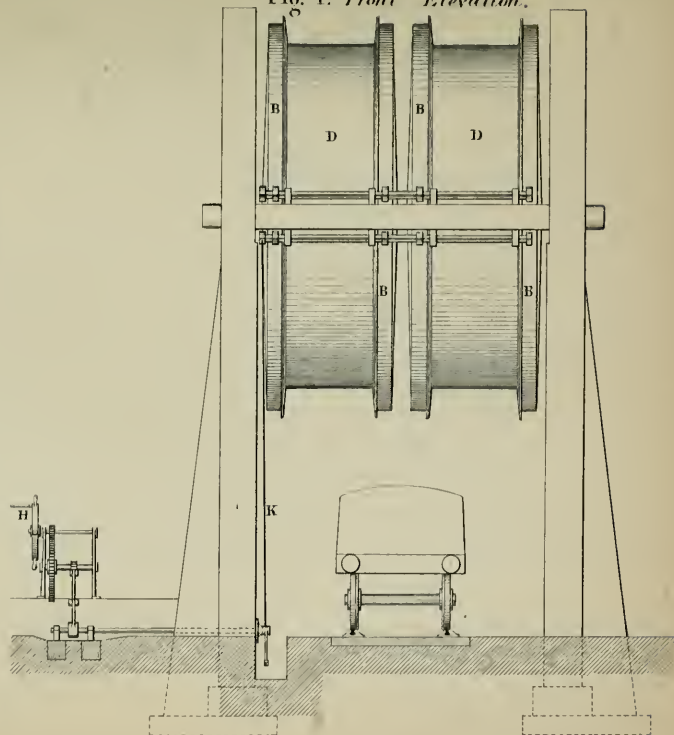


Fig. 4. *Front Elevation.*

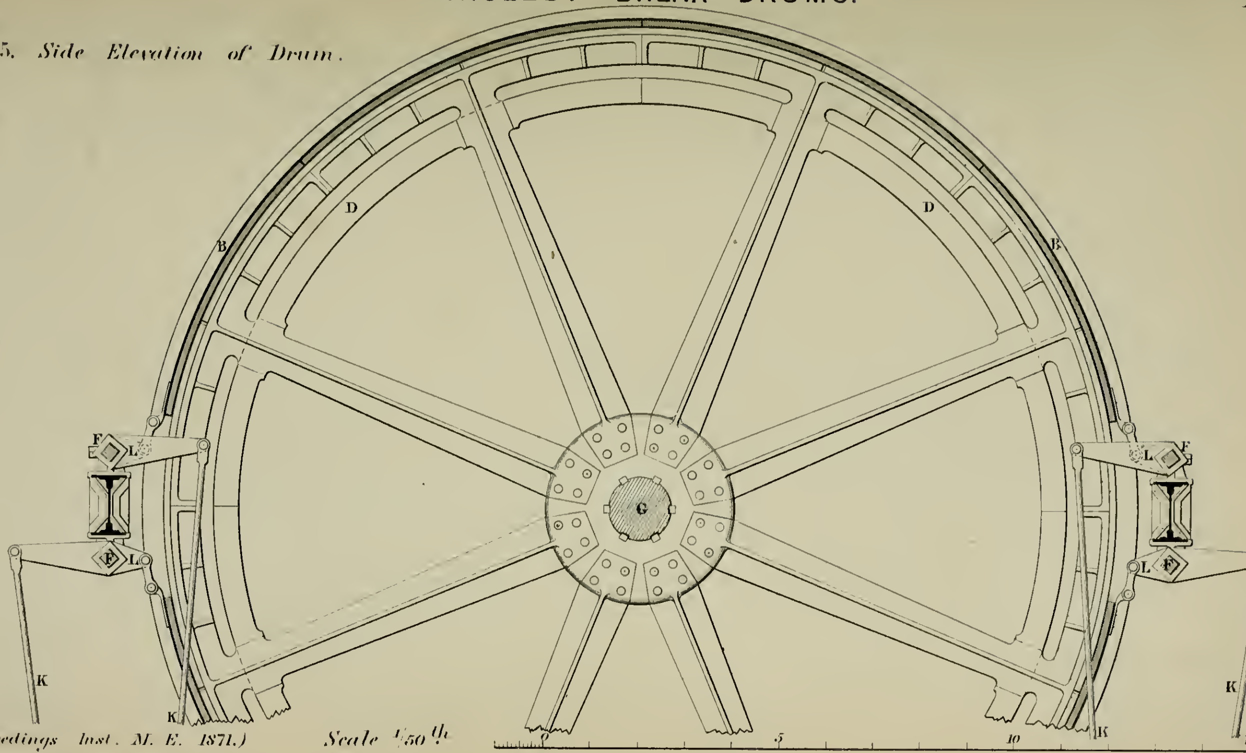


Scale 1/120th

(Proceedings Inst. M. E. 1871.)

INGLEBY BREAK DRUMS.

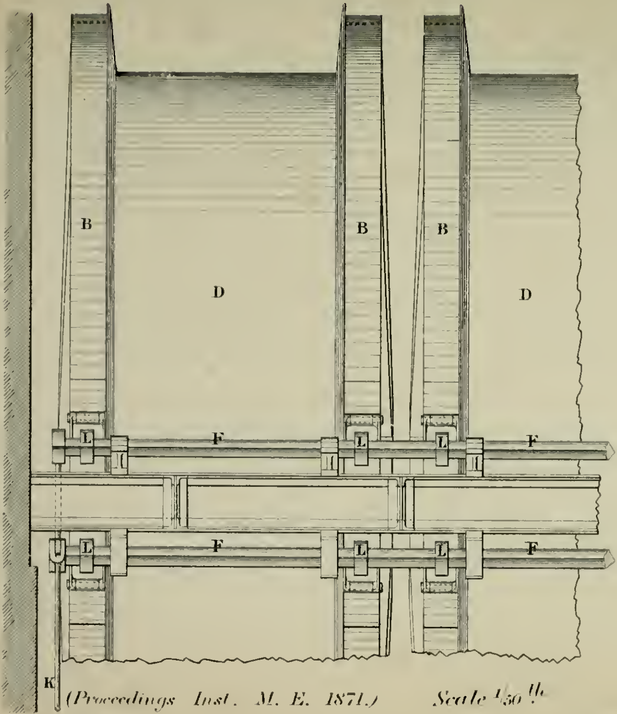
Fig. 5. *Side Elevation of Drum.*



(Proceedings Inst. M. E. 1871.) *Scale 1/50th*

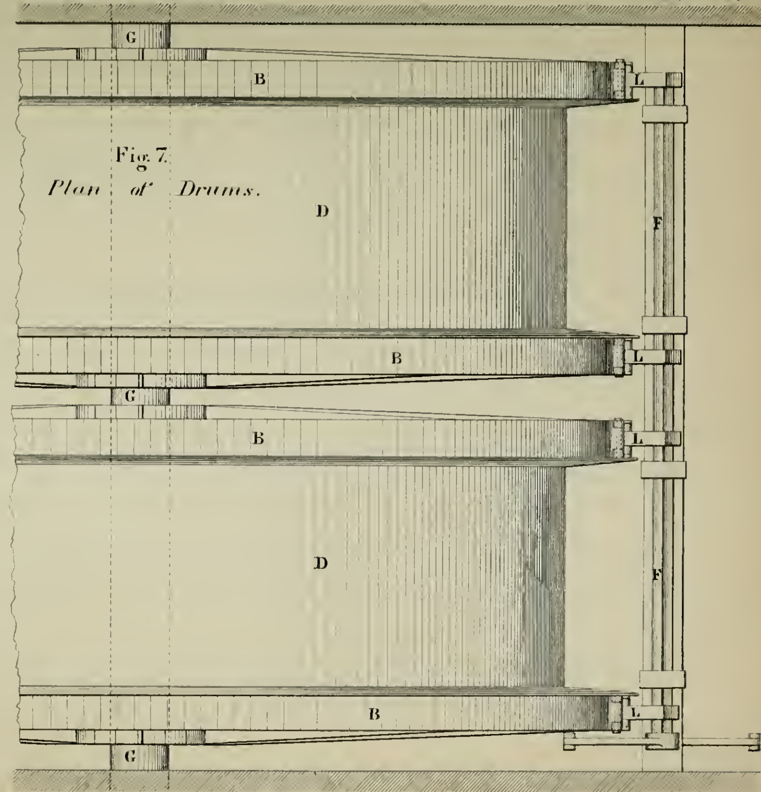
INGLEBY BREAK DRUMS.

Fig. 6. *Front Elevation of Drums.*



(Proceedings Inst. M. E. 1871.) *Scale 1/50th.*

Fig. 7. *Plan of Drums.*



INGLEBY BREAK DRUMS.

Fig. 8. *Elevation of Break Blocks and Rim of Drum.*

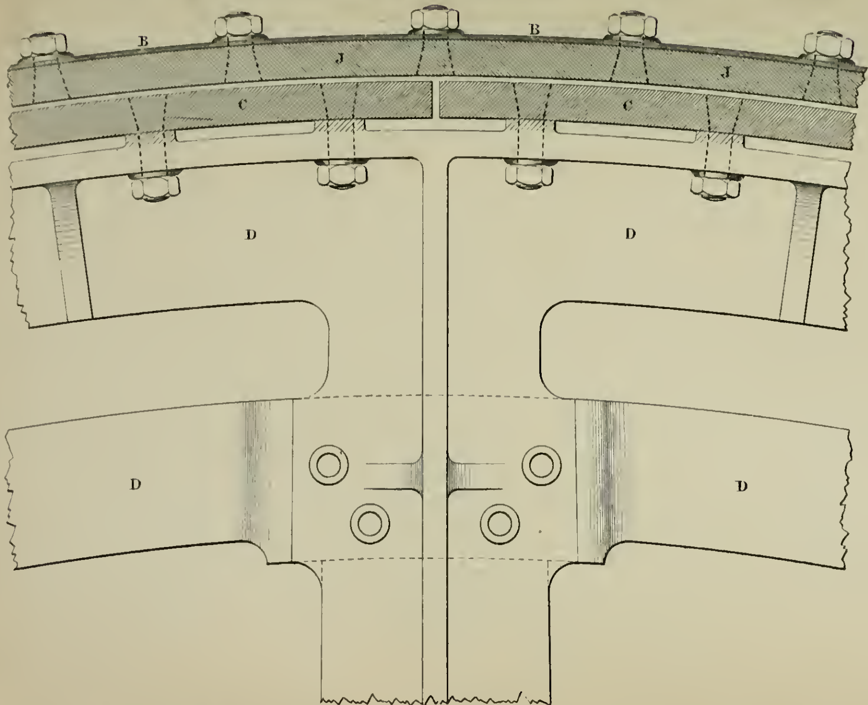
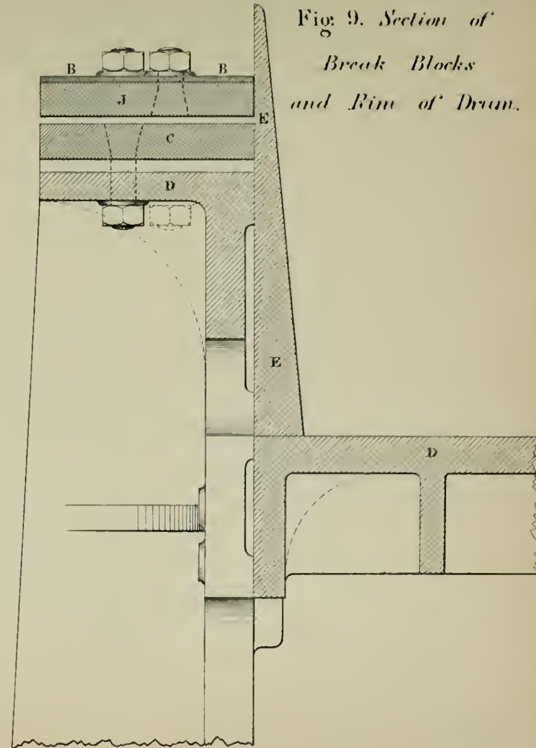


Fig. 9. *Section of Break Blocks and Rim of Drum.*



Scale 1/8th

0 5 10 15 20 25 30 *Inches.*

STEAM ENGINE GOVERNOR.

Fig. 1. *Diagram of Watt's Original Governor.*

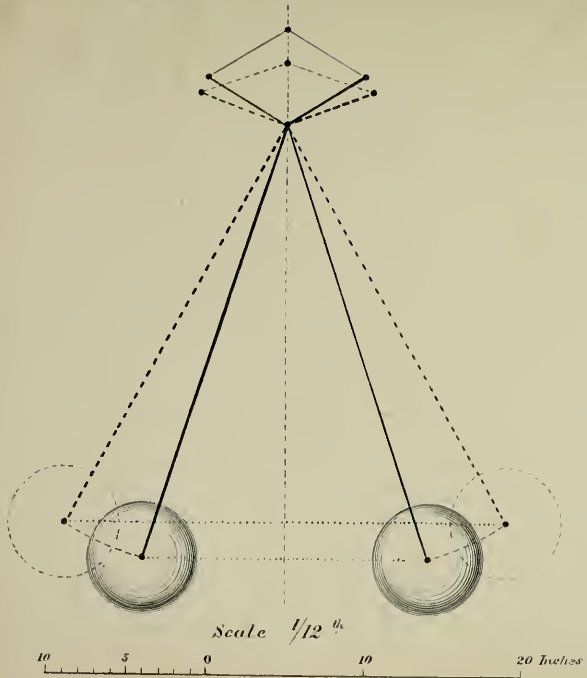
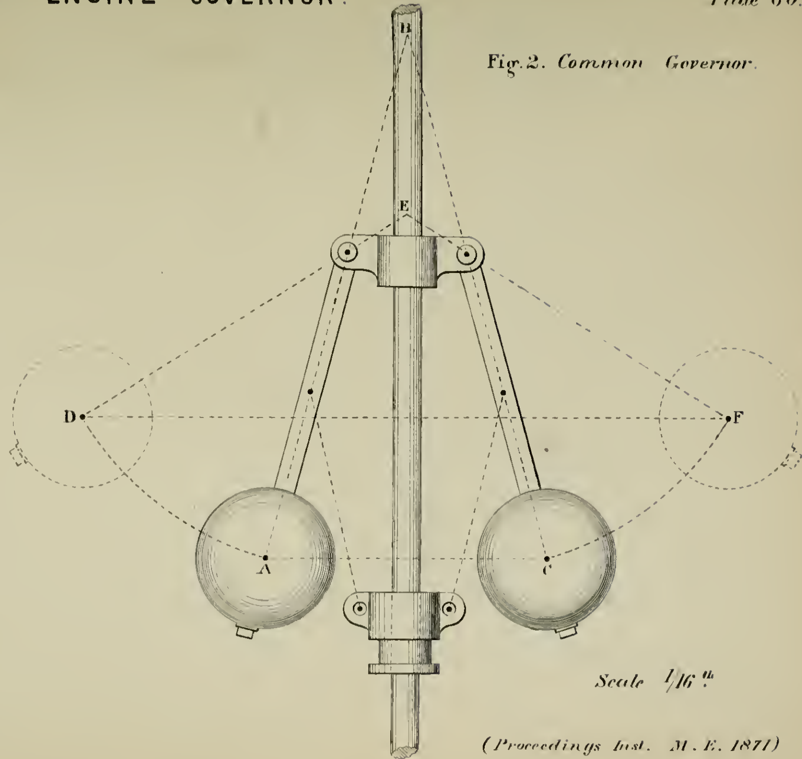


Fig. 2. *Common Governor.*



(Proceedings Inst. M. E. 1871)

STEAM ENGINE COVERNOR.

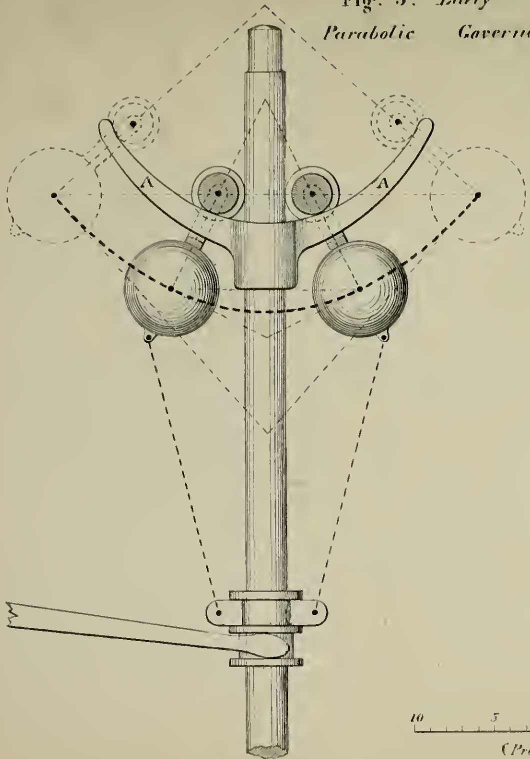


Fig. 3. *Early Parabolic Governor.*

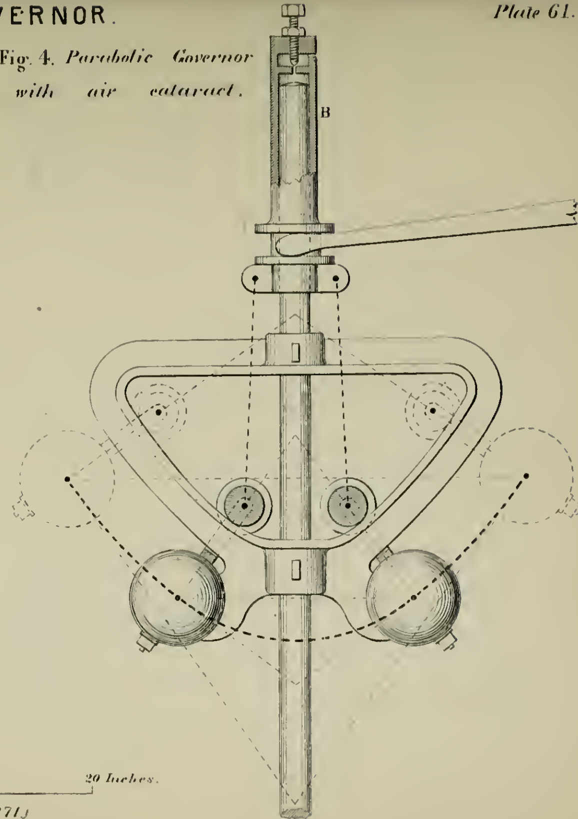


Fig. 4. *Parabolic Governor with air cataract.*

Scale $^1/_{12}$th

10 5 0 10 20 Inches.

(Proceedings Inst. M. E. 1871)

STEAM ENGINE GOVERNOR.

Plate 62.

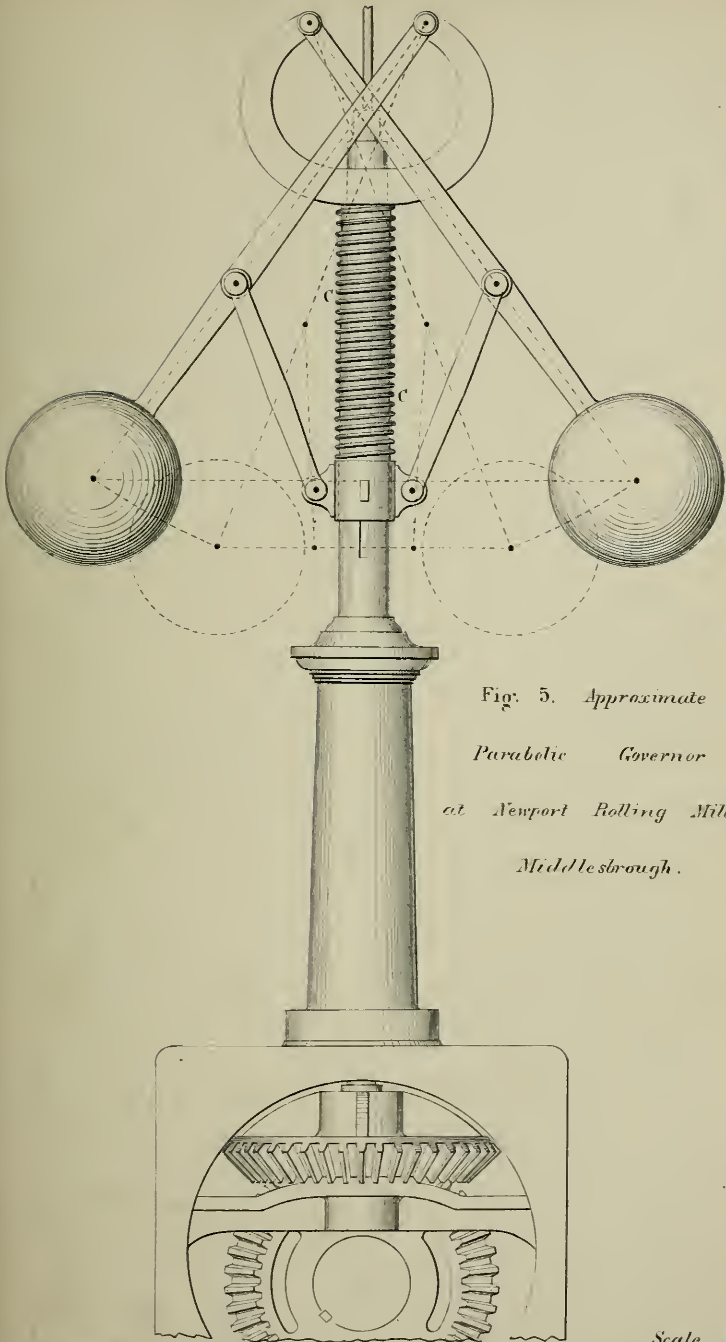


Fig. 6.

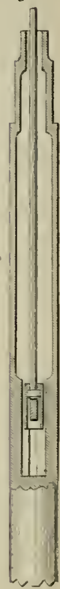


Fig. 5. *Approximate Parabolic Governor at Newport Rolling Mills. Middlesbrough.*

Scale $^{1}/_{12}{}^{th}$

(Proceedings Inst. M. E. 1871.)

10 5 0 10 20 30 *Inches.*

Fig. 7. *Diagram showing Parabolic Curve and approximately coinciding Circle.*

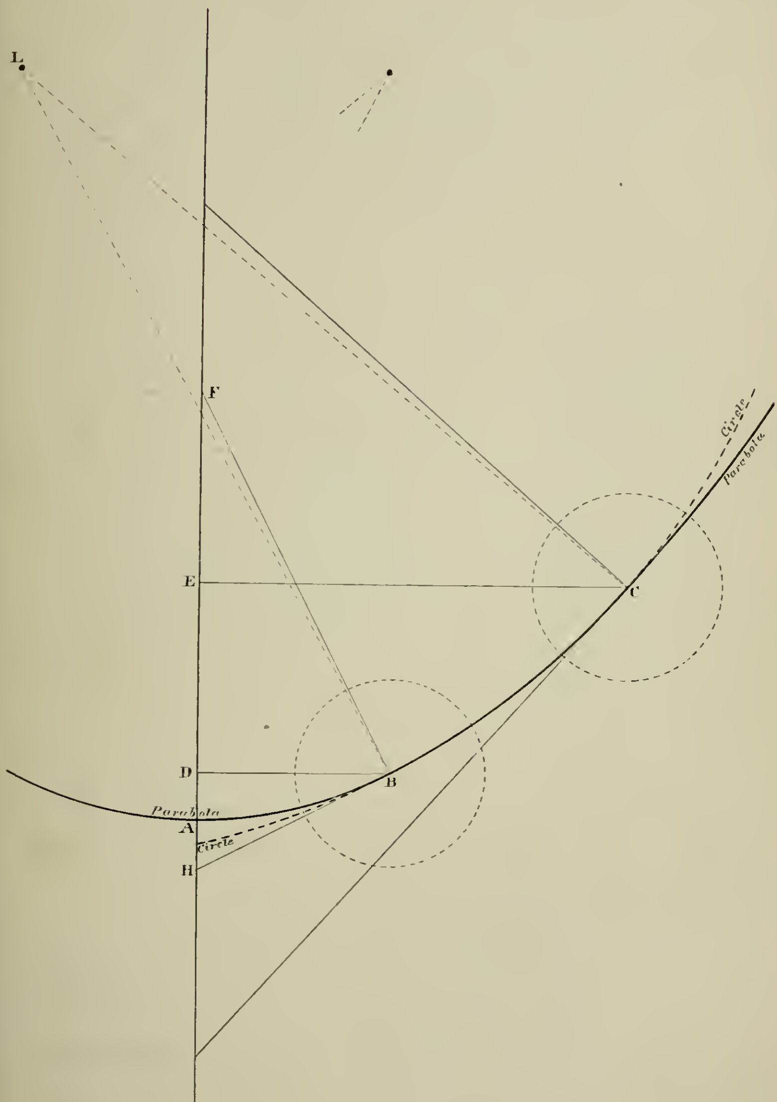


Fig. 1. *Woolf's Cast-iron Boiler. 1803.*
Tubes 12 ins. diam.

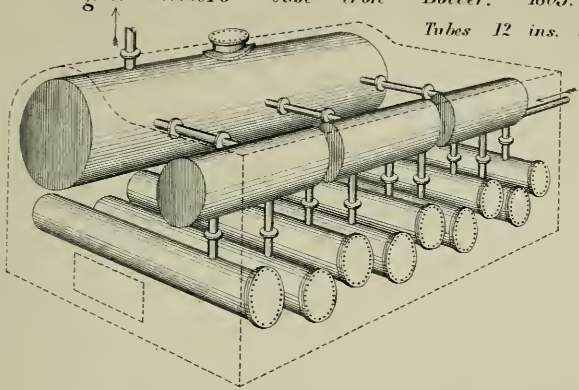


Fig. 2. *Hancock. 1825.*
Tubes 4½ ins. diam.

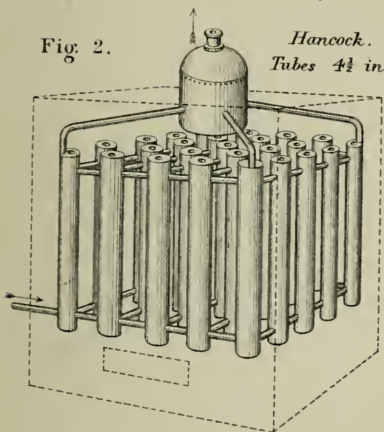


Fig. 3.

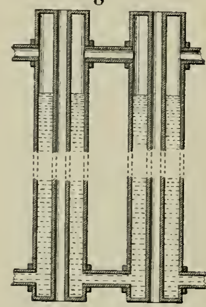
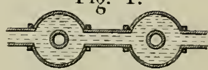


Fig. 4.



Ogle. 1830.
Tubes 4 ins. diam.

Fig. 5.

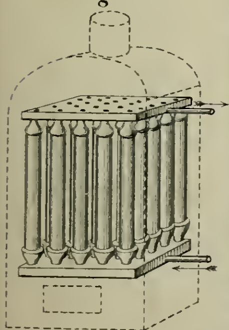
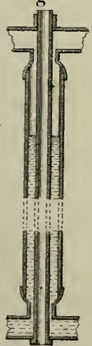


Fig. 6.



Hancock. 1827.

Fig. 7.

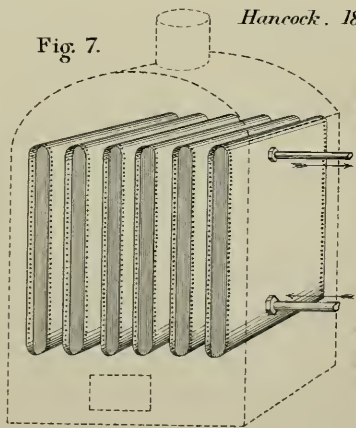
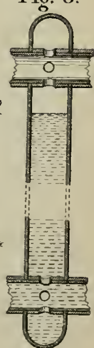
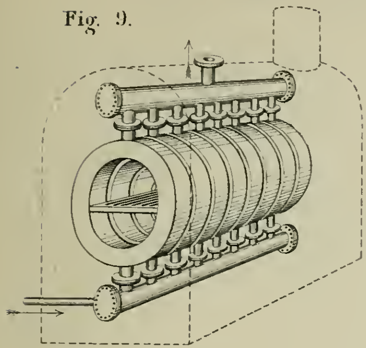


Fig. 8.



James' Cast-iron Boiler.
Rings 6 inches square.

Fig. 9.



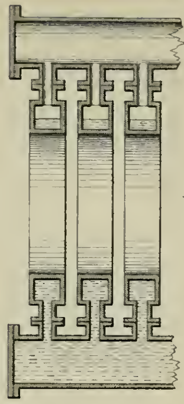
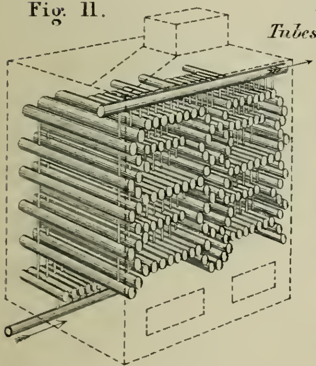


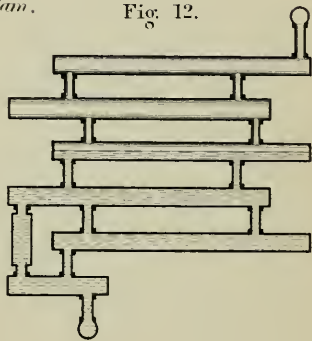
Fig. 10.

Fig. 11.



Perkins.
Tubes 2¼ inches diam.

Fig. 12.



Belleville.
Tubes 4 inches diam.

Fig. 13.

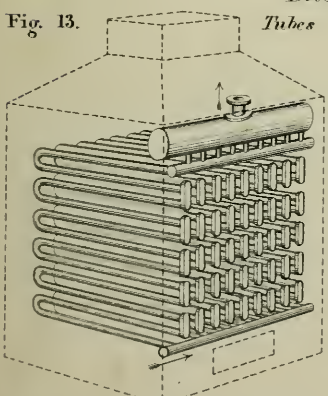
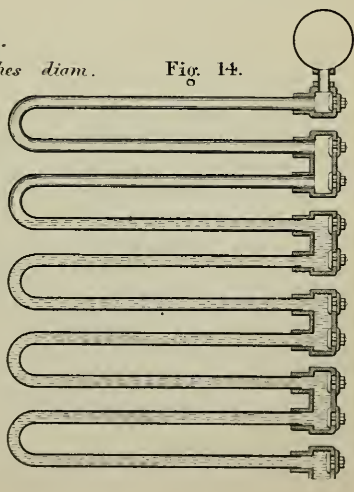


Fig. 14.



(Proceedings Inst. M. E. 1871.)

Jordan.

Tubes $8\frac{1}{2}$ inches diam.

Fig. 15.

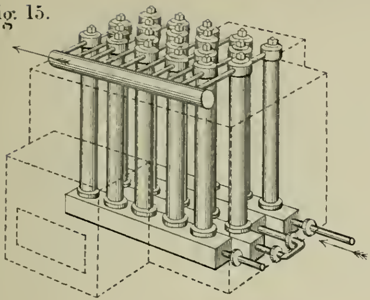
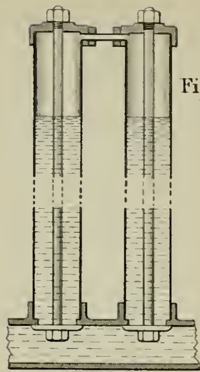


Fig. 16.



Harrison's Cast-iron Boiler.

Balls 8 inches diam.

Fig. 17.

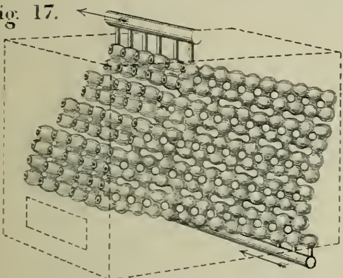
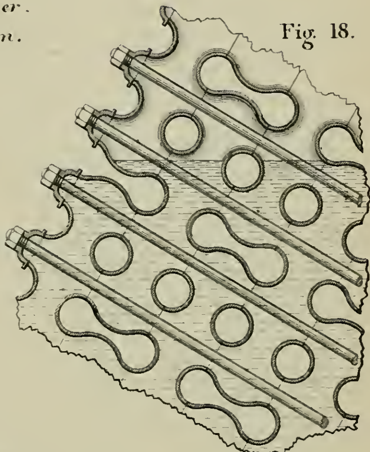


Fig. 18.



Benson.

Tubes $1\frac{1}{2}$ inch diam.

Fig. 19.

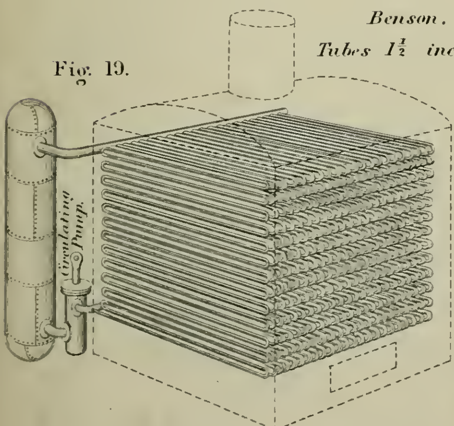
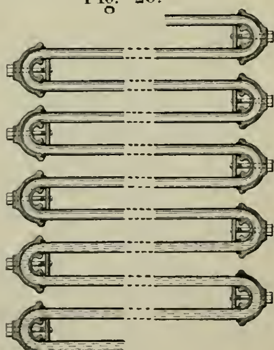


Fig. 20.



(Proceedings Inst. M. E. 1871.)

Field.

Tubes 4 inches diam.

Fig. 21.

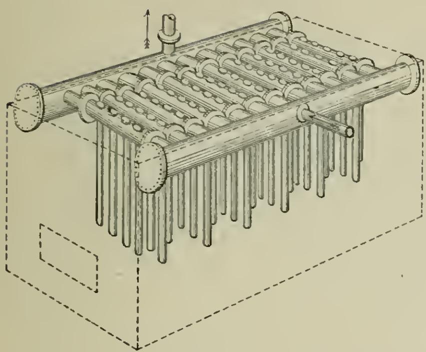
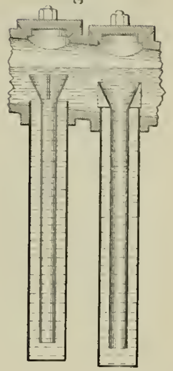


Fig. 22.



Howard.

Tubes 8 inches diam.

Fig. 23.

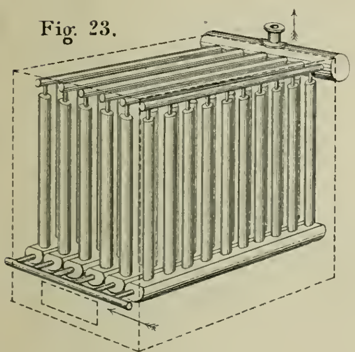


Fig. 24.

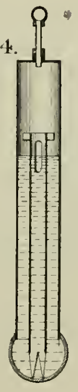


Fig. 25.

Allen.

Tubes 5 inches diam.

Fig. 26.

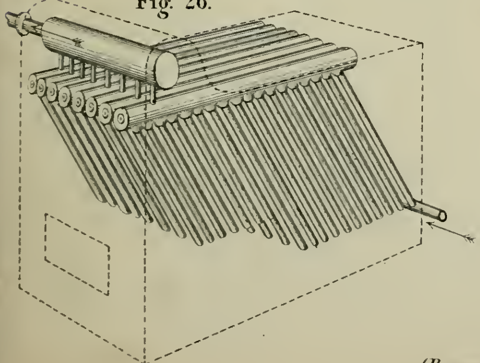
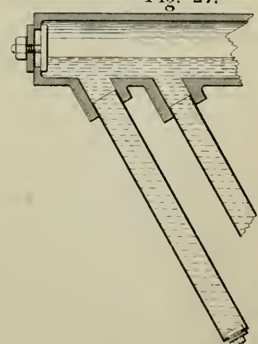


Fig. 27.



Root's Tube Boiler, at Ormesby Iron Works, Middlesbrough.

Tubes 4 ins and 5 ins. diam

Fired with Gas.

Fig. 28. *Longitudinal Section.*

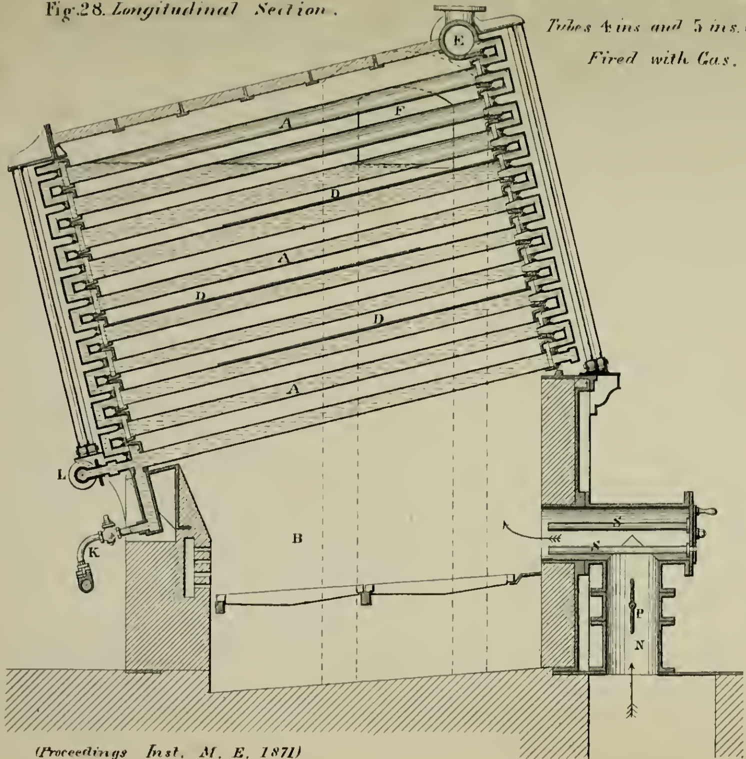
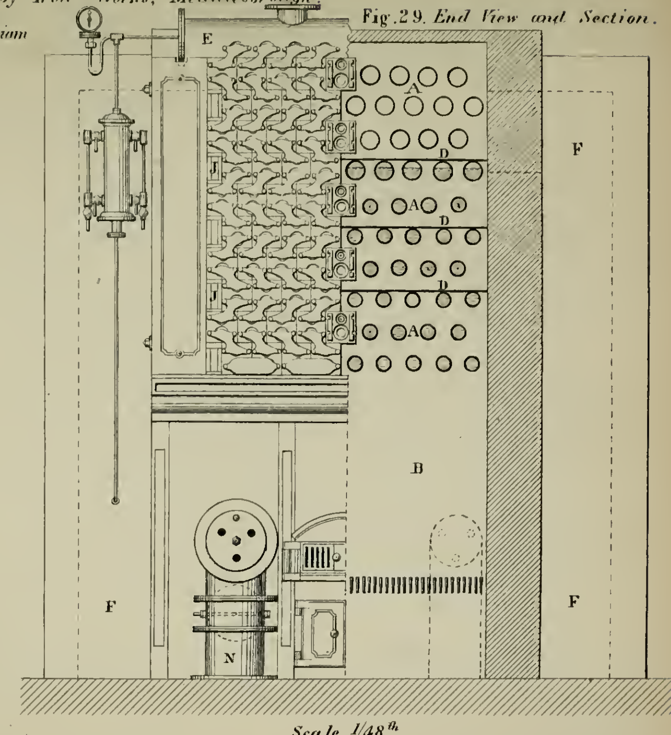


Fig. 29. *End View and Section.*



STEAM BOILERS.

Fig 30. *Longitudinal Section of Root's Tube Boiler.*

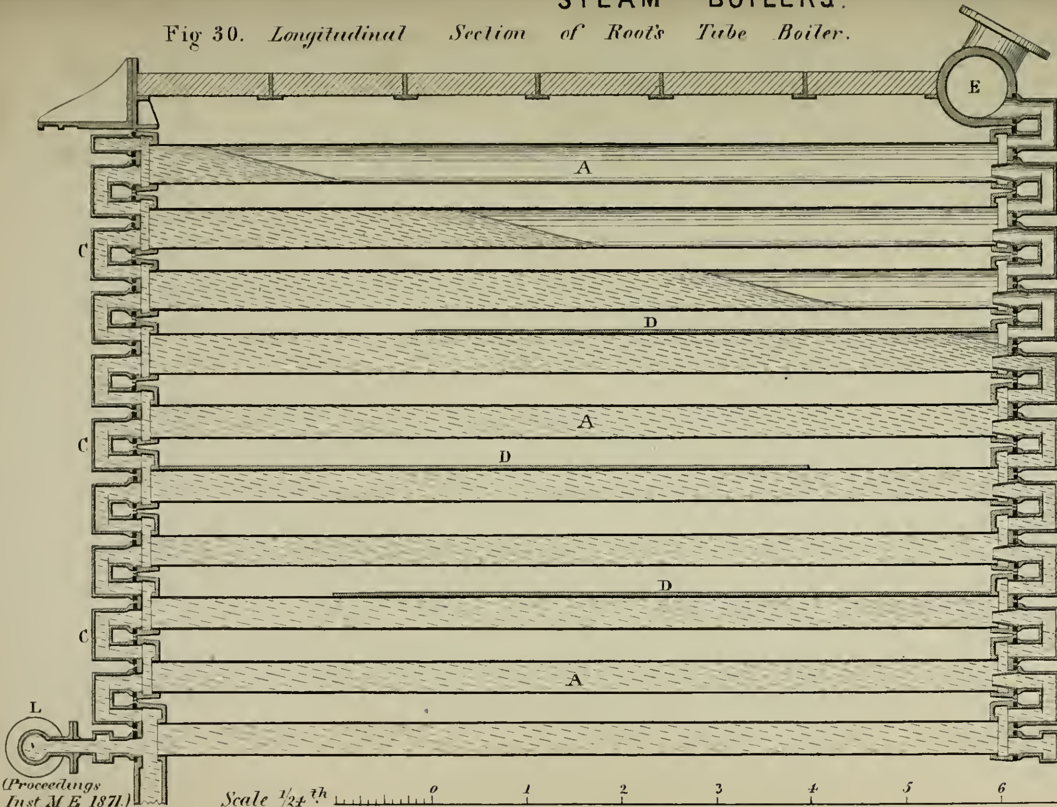
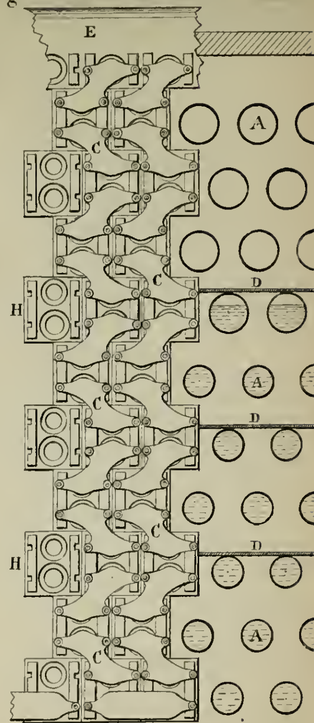


Fig 31. *End View and Section.*



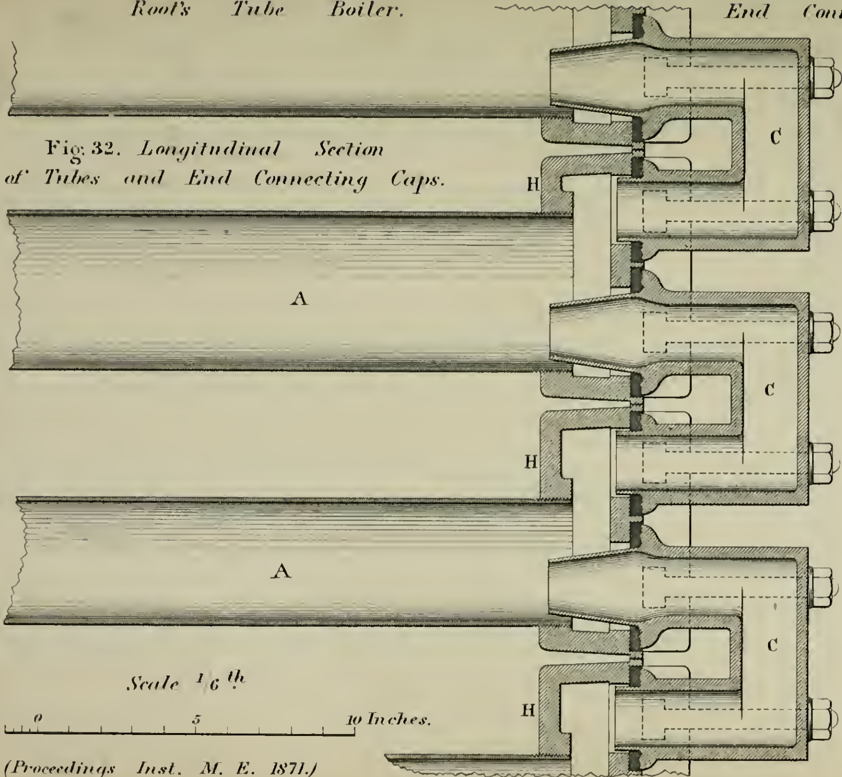
Scale 1/24th 0 1 2 3 4 5 6 7 8 9 10 Feet.

(Proceedings Inst. M E 1871.)

STEAM BOILERS.

Root's Tube Boiler. *End Connections of Tubes.*

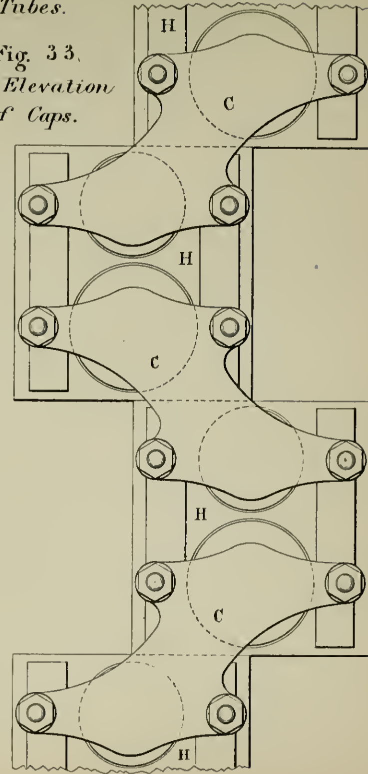
Fig. 32. *Longitudinal Section of Tubes and End Connecting Caps.*



Scale 1/6th

0 5 10 *Inches.*

Fig. 33. *End Elevation of Caps.*



(Proceedings Inst. M. E. 1871.)

STEAM BOILERS.

Root's Tube Boiler.

End Connections of Tubes.

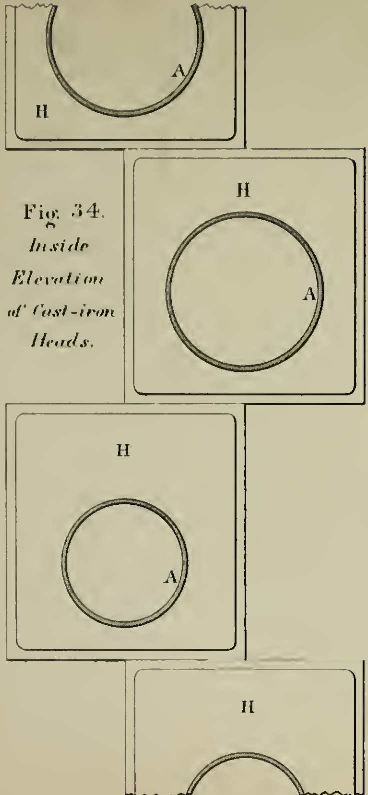


Fig. 34. *Inside Elevation of Cast-iron Heads.*

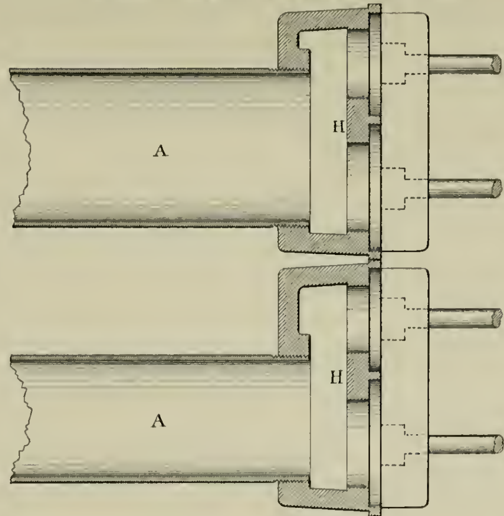


Fig. 35. *Longitudinal Section of Tubes and Cast-iron Heads.*

Scale 1/6th 0 5 10 *Inches.*

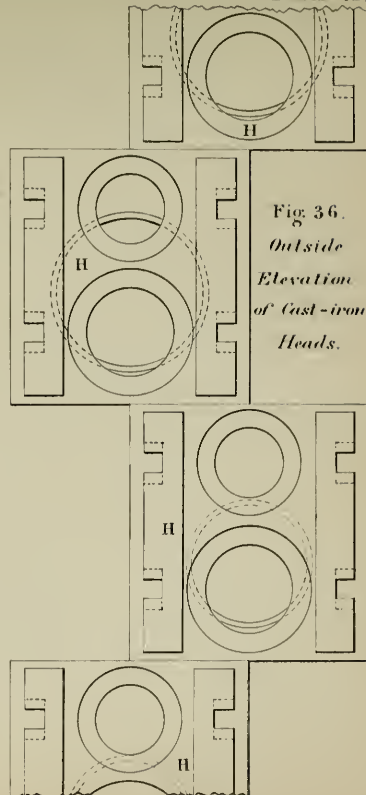
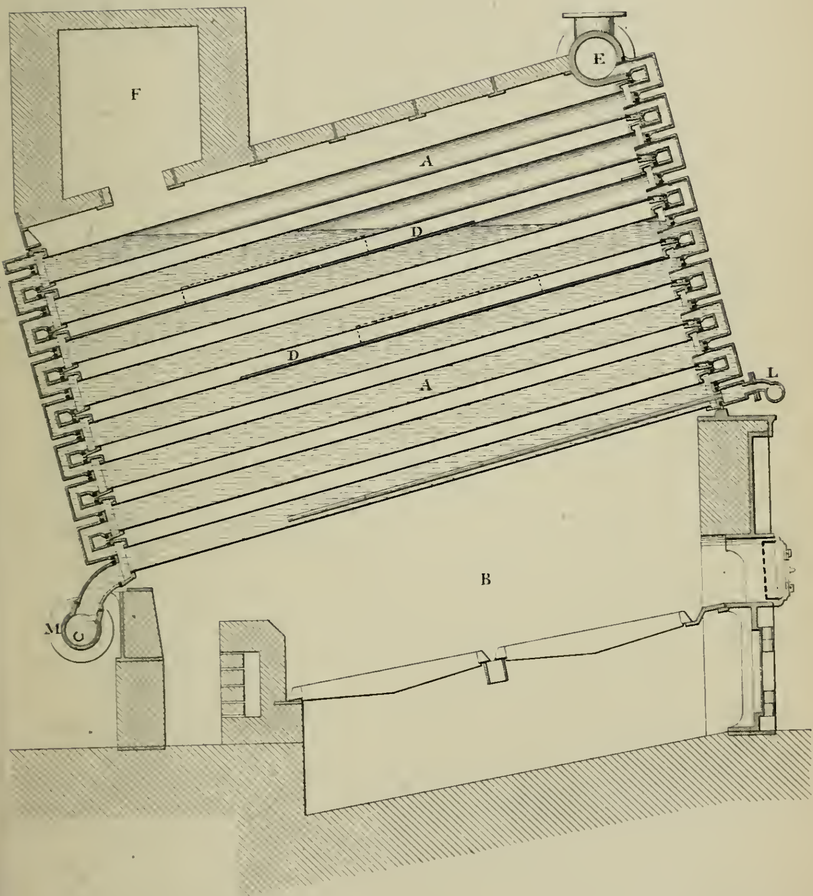


Fig. 36. *Outside Elevation of Cast-iron Heads.*

(Proceedings Inst. M. E. 1871.)

Root's Tube Boiler.

Fig. 37. Arrangement for firing with Coal.



Scale 1/36th

The Adjourned Meeting of the Members was held in the Oddfellows' Hall, Middlesbrough, on Wednesday, 26th July, 1871; John Ramsbottom, Esq., President, in the Chair.

The following paper was read:—

ON THE GENERAL GEOLOGICAL FEATURES OF THE CLEVELAND IRON DISTRICT.

By Mr. JOHN JONES, of Middlesbrough.

During the last twenty years the Cleveland hills have speedily risen into national importance as a vast mining centre, from which at the present time sufficient iron ore is annually extracted to produce about one third of the total quantity of pig iron manufactured in Great Britain. Previous to the year 1850, though it was well known to geologists that the liassic beds of North Yorkshire contained nodules and regular layers of ironstone, no systematic mining operations had been commenced, nor indeed was it at all understood that the deposits of ore were either extensive or valuable. The supply of ironstone from the coal measures of Durham, required for blast furnaces erected in the Tyne district, having failed in some instances, attempts were made to obtain a substitute from the ironstone nodules scattered along the Yorkshire coast. The ironstone was soon afterwards found *in situ* at Skinningrove; and further search being made northwards, the late Mr. Vaughan eventually discovered the now famous "main seam" of Cleveland ironstone in the face of the Eston hills. The importance of the deposit having been fully proved, the erection of blast furnaces on the banks of the Tees was soon commenced, and mining operations were pushed forward in various places where the ironstone cropped out. From that time to the present the industrial activity of the district has gone on increasing steadily, until it has become a most important manufacturing locality. In the present paper it is proposed to give a brief sketch of the geological features of the Cleveland district, and to point out the general characteristics of the mining operations and iron manufacture carried on there.

The Cleveland District is understood to include that part of Yorkshire situated north of the Whitby river Esk, the towns of Whitby and Stokesley forming approximately the eastern and western limits. The accompanying plans, Figs. 1 and 2, Plates 51 and 52, show the general geographical and geological features of the district, with the contiguous coal and limestone formations. In Fig. 2, A A denotes the mountain limestone; B B the millstone grit; C C the coal measures; D D the magnesian limestone; E E the new red sandstone; H H the lower lias; I I the middle lias, containing the main seam of ironstone; K K the upper lias, containing the upper ironstone seam; L L the great oolite; M M the coralline oolite; N N the Kimmeridge clay. The relative positions of the strata are shown in the vertical section, Fig. 3, Plate 53, which is taken through the Upleatham hill along the line X X in the plan, Fig. 2. With the exception of a narrow fringe of flat ground along the southern margin of the Tees, the whole district is very hilly. There are wide tracts of moorland towards the south, from which numerous valleys branch off, chiefly in the direction of the sea.

The lowest geological formation is the new red sandstone, which occupies the greater portion of the low ground along the southern bank of the Tees. The course of the Tees from near Darlington to the sea lies through the upper part of the triassic series, consisting of alternations of red marl with gypsum, and red and whitish sandstones. The characters of these measures have been ascertained by borings made in several places, where enthusiastic explorers setting aside geological facts have expended large sums of money in a fruitless search for coal. In the vicinity of Hartlepool the lower divisions of the series are brought up, a line of fault apparently traversing the district between Middlesbrough and Seaton.

These keuper marls of North Yorkshire have been proved to contain deposits of rock salt of considerable extent. Some years ago a boring for water was commenced by Messrs. Bolckow and Vaughan close to their Middlesbrough Iron Works, and eventually a mass of salt rock upwards of 100 feet in thickness was met with, lying at a depth of about 400 yards below the surface. The importance of this discovery was at once appreciated, as it was seen that the numerous

chemical works on the Tyne would afford a market for large quantities of Middlesbrough salt; and steps were accordingly taken for commencing the extraction of the salt. It was hoped that sufficient water would be found existing in connection with the salt rock, to allow of its being pumped up in the form of brine; and pumping machinery was put down for the purpose of testing this assumption. The plan not proving successful however, it was decided to sink a couple of shafts down to the salt; these are now in progress, and in the course of a short time it is expected that the work will be completed. A few miles east of Middlesbrough, near Eston and Lackenby stations, the top beds of the keuper contain considerable quantities of gypsum, which is being extracted for commercial purposes.

The triassic or new red sandstone measures shade up gradually into the blue shales and limestones of the lower lias formation, which forms the basement of the hills, and crops out in many cliff sections and in scars at and near the mouth of the Tees. From certain borings that have been made between Eston and Redcar it is tolerably well authenticated that between the top of the keuper marls proper and the lower lias, a thin series of measures exists representing the Penarth or Rhœtic beds, which have been clearly defined in various places in the south west of England, and have been traced to the north east as far as Gainsborough. The lower part of the lias does not present many features calling for special remark; it is in all essential particulars identical with the formation as exposed in different parts of the country towards the south west. The organic remains correspond broadly with those found in the south of England, and there is also a great similarity in the mineralogical composition of the measures. All this indicates that during the deposition of the lower lias of the English area the same geological conditions prevailed, though this similarity of conditions did not prevail when the next member of the series was laid down. Towards the top a considerable thickness of blue shale is found; upon this rests the middle lias or marlstone series, which is fully exhibited in cliff sections along the coast; the measures consist for the most part of sandy beds with partings and occasional layers of shale. A

good deal of iron is diffused through this series; irregular bands of ironstone occur at intervals; nodular masses are also found, and the whole formation is tinged a more or less deep shade of brown, from the oxide of iron dispersed through it.

It is in the top portion of this series that the Main Seam of Cleveland Ironstone is situated, from which the bulk of the ore now being smelted in this district is derived. This remarkable deposit is very persistent over the whole of the Cleveland district, as far as can be at present ascertained, though it is not uniformly of the same thickness or equally rich in iron. The stone is an impure carbonate of protoxide of iron, containing from 27 to 33 per cent. of metallic iron. This seam crops out along the northern slope of the Eston hills, where it attains its maximum development, being in places nearly 14 feet in thickness, and containing as much as from 32 to 33 per cent. of iron. Proceeding eastwards, at Upleatham the stone is found cropping out also, and there it is from 11 to 12 feet in thickness. At Hob Hill near Saltburn there is a small patch of ironstone with the same general characters as at Upleatham. The ironstone bed may be traced along the coast in various places, but beyond Skinningrove it begins to split up, and the percentage of iron is not so high. South west of Guisbrough the seam is much thinner, and at present the mines at Hutton Cross and Cod Hill in that locality are not worked. At Belmont and other places south and east of Guisbrough the stone improves in thickness and quality, and is extensively worked.

The principal mines in Cleveland are situated in the Eston hills, which with Ormesby and Normanby cover an area of from three to four square miles; and the mines also comprise a tract of country extending about six miles south east from Upleatham and Guisbrough and having an average breadth of about four miles. Over this area the ironstone has been for the most part proved, and large workings are being opened out along the southern margin of the district. This ironstone field is shown on the plan, Fig. 1, by the crossed shading lines. The best stone of Cleveland is now known to cover from 27 to 30 square miles; and at the present rate of extraction it is calculated that there is in this area sufficient stone to last the whole of the existing blast furnaces nearly a hundred years to smelt.

The following analyses of the ironstone represent approximately the composition of the ore :—

	Normanby.	Eston.	Upleatham.
Protoxide of Iron	38·06	39·92	37·07
Peroxide of Iron	2·60	3·60	4·48
Protoxide of Manganese . . .	0·74	0·95	...
Alumina	5·92	7·86	12·37
Lime	7·77	7·44	4·67
Magnesia	4·16	3·82	2·69
Potash	...	0·27	...
Carbonic Acid	22·00	22·85	23·46
Silica	10·36	8·76	10·63
Sulphur	0·14	0·11	...
Phosphoric Acid	1·07	1·86	1·17
Organic matter	...	...	...
Water	4·45	2·97	3·36
	97·27	100·41	99·90
Metallic Iron	31·42	33·57	31·97

Very little is known as to the character of the ironstone in the south east of Cleveland, but from the coast sections it may be inferred that the seam is split up into layers of various thicknesses by partings of shale. At Grosmont and in that neighbourhood the ironstone consists essentially of two seams, named after the principal fossils which they contain :—the "pecten" seam 4 ft. 6 ins. thick, with a shale parting of 1 ft. 6 ins. ; and the "avicula" seam 3 ft. 9 ins. thick, about 30 feet below the other. The percentage of iron is lower here than it is further north, besides which the extraction of the ore is much more expensive. It is an undoubted fact that there are many square miles of ironstone lying beyond the present active mining field above described, which will eventually be worked, but not to any large extent until the portions nearest to the coalfield have been exhausted. The ironstone contains considerable numbers of organic remains, large bivalve shells, ammonites, belemnites, &c. ; and hence analysis usually gives from $1\frac{1}{4}$ to $1\frac{1}{2}$ per cent. of phosphoric acid. In some parts of the district a seam of ore from 2 to 3 feet thick occurs only a few feet below the main seam ; this has not been worked at present. The main seam of ironstone is

overlaid by a small thickness of ordinary shale, which terminates the middle lias series; the total vertical depth of the marlstone is from 150 to 200 feet. In the south west of England this series thins out considerably; and though it is highly ferruginous throughout, it does not there contain sufficient iron to be of any commercial value.

The upper lias consists (in ascending order) of jet shale and alum shale, as shown in the section, Fig. 3, Plate 53. The former yields the jet of commerce, which is chiefly obtained from the Cleveland district, and more particularly in the neighbourhood of Whitby. The alum shale is a very persistent formation, which has been extensively worked for the purpose of being used in the preparation of common alum. The first alum works were started in the vicinity of Guisbrough, where the remains of extensive workings may still be traced; and in several places along the coast the manufacture is still carried on, though not on a large scale.

Near the top of the upper lias another seam of ironstone is found, which is called the "top seam" of Cleveland, and is shown in the section, Fig. 3. This is a variable bed, both in extent and richness; in some parts it is very thin, in others it opens out to a considerable thickness; in the Cleveland district proper it is not worked, but further south it is being developed. The character of the stone varies much; it is for the most part an impure oxide of iron, yielding in some places as much as 40 per cent. of metallic iron. In Rosedale this top seam is being largely extracted, and it has also been worked at Glaisdale near Whitby; but both these places are beyond the limits of Cleveland proper. Underlying the top seam at Rosedale are large deposits of a superior quality of iron ore, having magnetic properties, but these are being rapidly exhausted; they appear to be of a purely local character, and to have been formed previous to the deposition of the upper ironstone seams, which overlie the magnetic ore quite regularly.

As a general rule it may be said that the ironstone measures are not much disjointed by faults; but the undulations of strata cause the main seam to be found at very different levels in traversing the district from north west to south east, and in some places there are

indications of lines of fault that mark dislocations in the strata to a considerable extent. In the south west of the district the measures are penetrated by the great whin dyke, shown by the strong dotted line on the plan, Fig. 2, which runs in a direct line from the carboniferous limestone of Durham to a point a little south of Whitby, traversing in its course the carboniferous series, the permian, new red sandstone, lias, and oolite. This dyke of igneous rock maintains throughout its course a width of about 60 feet; it is a compact crystalline rock, and is extensively quarried in several places for road material. The rocks through which it passes are much altered for some distance on each side, varying according to the character of the measures; the effects are often apparent to 100 feet distance from the edges of the dyke. It has been assumed by some geologists that this igneous dyke has exercised a marked influence upon the character of the ironstone measures over large areas, rendering the stone comparatively lean; but this view seems to be unsupported by evidence, and is opposed to sound geological reasoning.

The main seam of ironstone attains its maximum development towards the north, where also it yields the highest percentage of metallic iron. Towards the south there is a gradual thinning out of the seam, until at length shale partings come in, splitting up the ironstone into thin bands, of which not more than two are workable. The percentage of metallic iron also gradually falls, until the stone becomes too lean to admit of its being used for smelting purposes. Indeed it may be asserted generally that at the present time a stone containing 24 per cent. of metallic iron may be regarded as of no practical value; and that each unit in the percentage of metallic iron above this point has a value of about 6*d*. per ton. Improvements in metallurgy may alter this standard from time to time, and therefore the statement must be taken as applicable only at the present period.

The undulations of the measures naturally cause accumulations of water in certain parts of the district, but on the whole the quantity of water that has to be pumped up in proportion to the tonnage of ironstone raised is very small. A great thickness of

impervious strata overlies the ironstone, so that ordinarily there is scarcely any water in the stone; but the measures beneath are more porous than those above, and when the stone lies in a trough or basin it occasionally happens that a good deal of water has to be contended with.

The marlstone and upper lias strata have suffered a good deal from denudation. An examination of the physical geography of the district shows that it must have been subjected to several alternations of level, and that a vast amount of material has been removed by marine and sub-aërial denudation. Over large areas the whole of the strata down to the lower lias have been swept out, forming wide valleys, as the vale of Guisbrough, and in the spaces between the Eston, Upleatham and Hob hills. The extent of this denudation has in some parts been much obscured by the subsequent deposition of drift clay and sand, during what is commonly known as the glacial period; a great thickness of this clay is found up to a level of about 120 feet above the sea, along the coast from Redcar eastwards.

The upper lias is overlaid by a considerable thickness of freestone, which is generally considered as the representative of the inferior oolite; and as a rule this freestone is found capping the high grounds of Cleveland. Beyond the limits of Cleveland proper, the higher members of the oolitic series come in; these contain a number of unimportant seams of ironstone, but in the neighbourhood of Castle Howard, about 40 miles to the south, somewhat extensive deposits of iron ore exist, which however are not sufficiently uniform in quality or rich in metallic iron to render them available for smelting purposes on a large scale.

It would seem then that the lias and oolitic strata of North Yorkshire contain immense quantities of iron ore in the form of impure oxides or carbonates. The richest tract however is in north Cleveland, where an ironstone averaging from 30 to 31 per cent. of metallic iron is now being raised to the extent of from 5 to 6 millions of tons per annum, and can be sold after allowing a fair margin for profit at from 3*s*. 6*d*. to 4*s*. per ton at the mines, the cost at the furnaces depending upon the expense of railway transit. In this part of the district the mines are within a few miles of the principal

smelting works, and are also comparatively near to the Durham coalfield. It is impossible therefore for many of the thinner beds of ironstone further south to be brought into successful competition with the north Cleveland mines; and hence large quantities of really valuable ironstone will have to remain unworked until the richer districts become partly exhausted.

Where the ironstone crops out along the escarpments of the lias hills, it is worked by means of day levels; in other cases shafts have to be sunk in the ordinary manner, but these do not generally exceed 600 feet in depth, whilst some are very shallow. The section in Fig. 3, Plate 53, of a small portion of the district, taken at X X in the plan Fig. 2, shows the mode in which the ironstone occurs in the Upleatham hills. The main seam is about 12 feet thick, and the bottom seam of about 2 feet thickness lies a few feet below. The position of the top seam of ironstone is also shown; in this particular locality it is only a trace, not suitable for working, but it thickens out further south.

The ironstone is worked upon the bord and pillar system, as shown in Fig. 4, Plate 54, which represents the mode of working where there are no interruptions from faults. A portion of the bed, from 2 to 3 feet in thickness, is left to form the roof of the workings; immediately below this is a shale parting, varying in thickness from a thin layer to 6 or 8 inches, largely impregnated with bisulphide of iron. In opening out a tract of ironstone the actual mode of working has to be varied according to the thickness of stone, nature of roof, and other circumstances; but when favourable conditions prevail, headways are driven at intervals of 30 feet at right angles to the main gate-roads, as in Fig. 4. The headways are made from 9 to 25 feet wide, and every 90 feet along them bords are excavated 25 feet wide at right angles to the headways. Thus pillars are left 90 feet long by 30 feet wide, or in some mines 90 feet square; and when the mine has been opened out to a sufficient extent, the working of the pillars is commenced, as shown at W, by removing them in a succession of "lifts" or courses of 12 feet width, as indicated by the fine dotted lines; the

stone is conveyed from the working faces to the winding shaft along the wagon ways shown by the strong dotted lines. Under favourable circumstances the whole of the ironstone, with the exception of from 7 to 10 per cent., is obtained by this system of mining.

In the most extensive mines it is necessary to lay down long engine planes for hauling the stone; the expense of haulage differs of course according to the dip of the strata, but generally the measures are not inclined at an angle of more than 5 degrees or 1 in 12, and the stone is brought to the bottom of the winding shaft or to the mouth of the day level at a trifling cost. When the stone is brought to the surface through day levels, it is customary to use large wagons with sloping sides, built either of iron or of wood; some of the iron ones are of considerable size, and they have flap doors in the bottom, through which the stone is let fall into the railway trucks; but the wooden wagons are generally tipped by means of a rocking cradle, upon which they are run and are then tipped bodily, the stone being thus shot down an inclined plane into the railway trucks. In the mines worked by shafts the ordinary tubs are used; a platform is provided at the top of the winding shaft, along which the tubs are run to proper shoots, and the stone is tipped into the railway trucks after it has passed over the weighing machine.

The ventilation of the ironstone mines does not present much difficulty. No explosive gas has to be contended with; the excavations are mostly very lofty and extensive, and a good current of air can be readily made to pass through the workings. In Fig. 4 the course of the air throughout the mine is shown by the arrows; S S are permanent stoppings in the different headways and bords, and D D are doors. Where the headways and bords are in process of being excavated, temporary wood brattices are constructed along them, for directing the current of air up to their extremities where the driving of the ends is in progress, as shown in the plan. At C C are air crossings, where the return current of air on its way to the upcast shaft is made to pass over the current of fresh air entering the mine from the downcast. At the Liverton mine, about 4 miles south east of Saltburn, a combustible gas has been met with, and is

now being utilised for illuminating purposes in the mine; the ironstone is there found to be impregnated with bituminous matter.

Though the Cleveland district proper has no coal measures within a workable distance of the surface, a few remarks may appropriately be devoted to the district from which the supplies of fuel required in the blast furnaces of the North of England are obtained. The triassic rocks which form the low-lying ground on the western margin of the Cleveland mining field are succeeded by the members of the permian formation, consisting of the magnesian limestone series, and sandstones. These form a belt of country stretching from the mouth of the Tyne to the south of Durham. They are in many places penetrated by mining operations, and the coal measures have been found to extend beneath the permian beds with tolerable regularity. Towards the south and south east however it appears that the coal measures crop out beneath the magnesian series, and hence it is highly probable that no connection exists between the coalfields of Durham and Yorkshire. That they once formed portions of a large area of coal measures may be regarded as certain; but it would appear that the upper carboniferous beds were removed over extensive tracts previous to the deposition of the secondary rocks, or even of the permian beds. In the south of Durham the boundaries of the coalfield eastwards from Cockfield near Auckland may be said to be pretty clearly defined; though there are still considerable areas in the south east of Durham and extending coastwise in the direction of Sunderland, which may eventually become part of the coalfield. The south western portion of the Durham coalfield yields several excellent seams of coal, which are well suited for producing coke of the best quality. The hardness of this material makes it well adapted to bear a heavy burden in the blast furnace; and when the metallurgical operations in Cleveland are studied, the character of the raw materials used in smelting must be taken into account.

The limestone used in the Cleveland blast furnaces is for the most part obtained from the carboniferous or mountain limestone of

the Pennine hills west of Durham. The principal quarries are at Stanhope, Forcett, and Merrybent, the last two places being much nearer to Middlesbrough than the first. Small quantities of oolitic limestone from the vicinity of Pickering, and of magnesian limestone from near Ferryhill, are also used; but the carboniferous limestone is much purer than the other varieties.

It will be noticed that the Cleveland iron district presents several features not usually met with in iron-making localities. The greater portion of the blast furnaces are situated near Middlesbrough and Stockton, on each side of the Tees; and they stand upon a geological formation that does not yield any of the minerals used in the smelting process. The ironstone is brought a distance of from 3 to 20 miles; the coal and coke are obtained from the South Durham coalfield, a distance of from 15 to 25 miles; and the limestone is brought distances varying from 20 to 40 miles. It is however found convenient and economical to fix the works near the river, as this affords greater facilities for sending the manufactured iron away.

In conclusion a few statistics may be added to show the extent and importance of the iron trade of this district. The total number of blast furnaces is 125, of which 119 are in blast; and 14 additional furnaces are now in course of erection. The total make of pig iron during last year 1870 was 1,695,377 tons. Up to this time a large increase has taken place during the present year, in consequence of the blowing in of additional furnaces, and the make for the month of June was 155,912 tons or at the rate of 1,870,944 tons per annum; and taking into account the new furnaces, it is estimated that the total make for this year will be upwards of two millions of tons. Allowing for the consumption of hæmatite and other imported ores, the present rate of consumption of Cleveland ore cannot be much less than at the rate of 5,750,000 tons per annum. The coal and coke used amount to about 2,500,000 tons, representing altogether nearly 4,000,000 tons of coal, or about one sixth of the total produce of the coal mines in the North of England.

Mr. Jones exhibited a large model of the Cleveland district, kindly lent for the occasion by Mr. John Bell, by whom it had been constructed. He showed also a number of specimens of the different members of the ironstone seam; and of the organic remains found principally in the bottom band of the main ironstone, consisting of fossil wood, bivalves, belemnites, and ammonites, all of which, however interesting and valuable from a geological point of view, were more or less detrimental to the value of the ironstone for smelting purposes. The shale parting in the upper portion of the main seam of ironstone consisted largely of bisulphide of iron. The great whin dyke running entirely through the district from the north-west to the south-east scarcely varied in appearance throughout the whole length of its range, as shown by the specimens exhibited of igneous rock taken from the two extremities of the course of the dyke; but there was a slight variation in its chemical composition in different places.

Mr. J. Marley thought the paper which had been read gave a very good general outline of the Cleveland ironstone district. He began to work the ironstone at Eston in the year 1850 for Messrs. Bolckow and Vaughan, and previous to that time he had obtained some of the ore for them in 1848 from the outcrop of the seam, and had shipped it from Skinningrove to the blast furnaces at Witton Park Iron Works near Bishop Auckland.

Mr. J. F. Wilson enquired whether any opinion had been formed by the author of the paper as to the probable extent of the salt deposit which had been met with in the borehole put down in Middlesbrough by Messrs. Bolckow and Vaughan; and whether it was thought the salt was likely to be found nearer the surface elsewhere than had been the case in the present boring.

Mr. A. L. Steavenson remarked that, from his own experience in mining the Cleveland ironstone for a number of years past, he thought it was seldom that the strata were found lying so level as they were represented in the section exhibited of the Upleatham hill. At the western end of the Eston hills the ironstone had a dip of about 5 inches per yard, and in many other places the dip was at as great an inclination. At the Normanby mines the outcrop of the ironstone

was 300 feet above the sea level, and they had now followed it down to the sea level, and had found that point was the bottom of a basin formed by the strata, the ironstone then rising again towards the south. For draining the mine at that inclination and depth, they had adopted Fowler's clip drum with complete success; and this was the first mine in the district at which that plan of pumping had been introduced. The removal of the pillars in working the ironstone mines was attended with much difficulty, on account of the soft nature of the superincumbent strata. In coal mines the roof was generally of hard stone, and was therefore easily kept from breaking down at the working faces by supporting it at a suitable distance behind with props. But in the Cleveland ironstone mines the roof was composed of 200 feet thickness of soft shale, which was so soft that it broke down between the props and the working face; and very great care was therefore necessary in getting the pillars. The thickness of the seam was also a source of great difficulty, and where it was only 7 feet thick it could be worked more easily and cheaply than where it was 12 or 14 feet thick. A great deal of the ironstone was got by day levels, and there was not much machinery in the mines themselves; but in many instances there were large pumping and winding engines at the surface. At the Normanby mine he had put up a Guibal fan for ventilating the workings, the depth of the shaft being not more than 20 fathoms, and the drag of the air through the mine being very slight. In such cases he considered furnace ventilation entirely out of place, as the efficiency of the furnace increased with the depth of the shaft; and the value of the coal consumed added seriously to the cost of furnace ventilation in any other mines than collieries. At the Lofthouse mine at Skinningrove one of Cooke's rotary ventilators was about to be put up, the results of which it would be interesting to know when the machine had been got to work.

Mr. C. W. Siemens enquired whether there was found to be any material difference in the quantity of phosphoric acid contained in the upper and lower bands of the main ironstone, on account of the greater quantity of organic remains occurring in the lower band; and

he asked whether the two bands had ever been worked separately, and whether pig iron made from the upper band alone had been found more free from phosphorus than that made from the mixed ore obtained from both portions of the seam.

Mr. J. Whitley enquired whether any conjecture had been formed as to the means by which the deposit of iron was made in the bed of the ocean, at the period when those strata were laid down.

Mr. Jones said that, with regard to the probable extent of the salt deposit which had been met with in the boring at Messrs. Bolckow and Vaughan's, there was a difference of opinion as to how the salt had been deposited, though the generally received view was that it had originally been in lagoons, from which the water had afterwards been evaporated, leaving the salt deposited there. Nothing definite however was at present known; and although the deposit had been proved by the boring already executed to be of considerable thickness at that place, he doubted whether it would be found to extend to any great distance on either side. The salt had not yet been raised in the form of rock salt, but a shaft was now being sunk for the purpose of getting it in that way; meanwhile some of it had been pumped up through the borehole as brine, and the salt had then been obtained by evaporation.

In reference to the general evenness of the ironstone seams as represented in the section shown through the Upleatham hill, it was impracticable in a general geological section to include all the minor dislocations that were met with in actual mining in any particular locality, but the more important ones were shown in the section. It was natural to expect that such dislocations and irregularities of level would be more marked near the outside boundaries of the strata; and as the Eston mines, which had been referred to, were situated on the extreme western confines of the ironstone district, it was not surprising to find the seam lying less evenly there than in the Upleatham hill, where the general position of the ironstone was about as nearly level as was represented in the section shown; taking the district as a whole, the ironstone seams lay generally very evenly.

The bottom band of the main ironstone seam, containing a greater quantity of organic remains than the upper part, would no doubt contain more phosphoric acid; and if the bottom part were left in the mines and only the top part worked, no doubt the pig iron produced from the latter would contain rather less phosphorus than when the stone was obtained from the whole thickness of the seam. The bottom part of the seam however was too valuable to be left behind in the mines, and it was therefore impracticable to procure for the blast furnaces a supply of ore from the top part alone.

How the iron ore originally got into the liassic ocean there was no means of knowing, but his impression was that it was not there at the time when the lias deposit itself was laid down; and he thought the present seam of ironstone had been originally deposited as a stratum of carbonate of lime, and that the lime had subsequently been replaced by iron. The ironstone seam exhibited the oolitic structure, which led him to believe that the greater part of the iron had taken the place of carbonate of lime and had been deposited by impregnation some time after the superincumbent beds had been consolidated; but how this had been done he was unable to say.

The President remarked that he had not previously had an opportunity of realising the great extent of the mineral resources of the Cleveland ironstone district, and from the information in the paper now read he had no doubt the prosperity of the district would continue to increase as it had hitherto done. It was very gratifying to be assured that there was a supply of ironstone sufficient to last for so long a period to come; and it was also highly satisfactory to find a new branch of industry likely to be opened up in the same neighbourhood by the recent important discovery of the salt deposit.

He moved a vote of thanks to Mr. Jones for his paper, which was passed.

The following paper was then read:—

DESCRIPTION OF THE BREAK DRUMS AND THE MODE OF WORKING AT THE INGLEBY INCLINE ON THE ROSEDALE BRANCH OF THE NORTH EASTERN RAILWAY.

By Mr. JOHN A. HASWELL, of Newcastle-on-Tyne.

The Rosedale mineral branch of the North Eastern Railway, which runs into the main line at Ingleby Junction, is used for the conveyance of ironstone from the mines at Rosedale in North Yorkshire, worked on both sides of the valley, near Rosedale Abbey. The Ingleby Incline, forming a portion of this branch, is $\frac{3}{4}$ mile long, with an average gradient of 1 in $5\frac{3}{4}$, the steepest portion being 1 in 5, as shown in the general section, Fig. 1, Plate 55. The loaded trains descend the incline, drawing up at the same time the empty trains; and a passing place for the two trains is made in the middle of the length of the incline, by a short length of double line, as shown in the plan, Fig. 2; the rest is laid with three rails, the centre one being common to both up and down trains.

The incline is worked in the usual manner of similar steep mineral inclines, by means of a pair of break drums fixed upon a horizontal shaft, and situated at the top of the incline. The drums and break gear are shown in Figs. 3 and 4, Plate 56. The descending train of loaded wagons pulls off the rope from one of the drums D D, and winds up that on the other drum, thereby drawing the return train of empty wagons up the incline. The speed is controlled by powerful breaks upon the drums, each drum being provided on both sides with a pair of break straps B B tightened up by levers; the weigh-shafts of the levers are coupled together by means of connecting-rods and bell-cranks, as shown in Fig. 3, so that the whole of the break straps are tightened or slackened simultaneously by a hand-winch H.

The drum barrels D D are 18 feet diameter and 4 ft. 8 ins. long, as shown to a larger scale in Figs. 5 to 7, Plates 57 and 58; they are made of cast-iron $1\frac{1}{2}$ inch thick, and are put together in four segments, which are bolted together by flanges; chipping pieces are cast on the faces of the flanges, and the segments are thus fitted together so as to form the circumference of the winding barrel with complete accuracy. There are eight cast-iron arms on each side of the drum, which are bolted to the side flanges of the barrel, as shown in Figs. 8 and 9, Plate 59; each arm has a corresponding segment of the rim cast with it, Figs. 5 and 8, and the flanges of the rim joinings are made with chipping pieces slotted or planed, and bolted together, as shown in Fig. 5. The outer circumference of the rim has chipping pieces at equal distances all round, which are accurately turned up for the reception of the cast-iron break-blocks C C, as shown in Figs. 8 and 9; and the blocks are bored out to the same diameter, and bolted upon the rim by countersunk bolts. The break-blocks are in eight segments round the circumference of the rim, and are fixed so as to cover the rim joints, the ends of the segments coming over the centre of each arm; a space of $\frac{1}{4}$ inch is left between the ends of the segments, as shown in Fig. 8, to allow for expansion. The inner ends of the arms are fitted with chipping pieces into a cast-iron boss, and securely bolted in their places by turned bolts fitting in bored holes, as shown in Fig. 5. In putting the drums together, after the arms had been fitted into the bosses and the rims firmly bolted together, these parts were laid on each side of the barrels, and the arms were carefully fitted between the cheeks cast on the side flanges of the barrels, as shown in Figs. 8 and 9; and the bolt-holes were then drilled through the flanges, steel wedges being driven in where necessary to make the joinings all perfectly tight. The shield-plates E, Fig. 9, cast in segments, are bolted to the inside of the arms by countersunk bolts.

The wrought-iron shaft G, Figs. 5 and 7, carrying the drums, is forged from best-selected scrap, and is 15 inches diameter with journals 18 inches long; it is turned the whole length, and has key-beds cut in it for securing the bosses of the drums, which are

bored out to the exact diameter of the shaft. The plummer-blocks are fitted with brass steps, $1\frac{3}{4}$ inch thick at the bottom and 1 inch at the sides; and each block is secured to the masonry by wrought-iron bars and holding-down bolts.

The wrought-iron break straps are made in halves, and extend round both sides of each drum, as shown at B B in Figs. 3 to 7. They are lined with cast-iron break-blocks, fastened by countersunk bolts, as shown at J J in Figs. 8 and 9, and these blocks are bored out to fit the corresponding turned blocks C C on the rim of the drum. The weigh-shafts F, Figs. 5 to 7, carrying the break levers L, are supported upon wrought-iron girders built into the side walls of the drum house. The short arms of the levers L are 9 inches length, and the long ones 24 inches; the bolts through all the eyes are $1\frac{1}{8}$ inch diameter. The vertical connecting-rods K, Figs. 3 and 5, from the weigh-shaft levers to the bell-cranks below, are provided with right-and-left-handed screws for adjusting them to the exact length required; and the two bell-cranks are coupled together by a horizontal connecting-rod M. The hand-winch H, by which the break power is applied, works a rack upon a horizontal flat-rod carried upon rollers, which is attached to an arm upon the shaft of one of the bell-cranks; and the whole of the breaks are in this way acted upon simultaneously by the winch.

The two break drums weigh together 68 tons, and the shaft, carriages, and break segments about 26 tons, making a total weight of 94 tons. The ropes are 5 inches circumference, made of steel wire, and are each 1650 yards long, weighing 8 tons. The rope end is taken through a hole in the side of the drum barrel, and wound two or three times round the shaft, and secured by a loop knot. The rope is not guided upon the drum in winding up, and there are three layers of coils of rope on the drum when fully wound up. The rope is supported off the ground by a series of carrying rollers on the incline, and is guided at the top and bottom of the passing place by guiding sheaves. A tail chain 12 yards long, made of 1 inch iron, is attached by a shackle to the free end of each rope; and to each tail chain is attached a riding chain 2 feet

long, made of iron $1\frac{3}{4}$ inches diameter. This riding chain is furnished with a hinged disengaging hook, for the purpose of enabling the men to disconnect the rope from the trains either at the top or bottom of the incline, when the rope is tight.

At the top of the incline the centre or loaded-wagon line, which runs under the drums, is inclined downwards 1 in 30 from the drum house to the top of the incline, as shown by the full line at A in Fig. 1, Plate 55, for enabling the loaded train to start of itself, the drum house being 200 feet distant from the top of the incline. The two side lines on the contrary, for the arrival of the ascending train of empty wagons, rise 1 in 66 from the drum house to the top of the incline, as shown by the dotted line at A, so that the wagons in the sidings remain safe, without any danger of their running back over the top of the incline. A series of pairs of inclined lateral chocks are fixed at intervals between the rails of the centre or loaded-wagon line; and the whole of these chocks are coupled together and worked by a single hand-lever, by which they are pressed outwards to rub against the wheels of the wagons, so as to check the speed of the loaded wagons at starting, until the drum rope is attached to them. In their extreme position the chocks can completely block the line, and are securely locked in that position by a toggle joint in the rod working each pair of chocks.

The ironstone from the mines is conveyed down the incline in iron hopper-wagons, each of which weighs on an average 5 tons empty, and carries about 8 tons of ironstone, making a gross weight of 13 tons. Four of these wagons compose a train load down the incline, giving an aggregate of 52 tons run down at one time. The counteracting load brought up the incline in ordinary working consists of five empty hopper-wagons, weighing 25 tons; but as materials for the mines, such as coal, timber, &c., have to be taken up, the up load may consist of one, two, or more wagons, the collective weight of which however is limited to 25 tons. The weight of the down load, 52 tons, is generally sufficient to start the drums and set the up train of 25 tons in motion, before the loaded train has passed over the top of the incline; but sometimes the loaded wagons require to be started by pinching with iron levers. After

the loaded train has passed over the top of the incline, it acquires an accelerating motion, which has to be controlled by the application of the break; but on approaching the bottom of the incline the break is released, so that the empty train may be landed over the top of the incline. After the loaded train is landed at the bottom of the incline, and the empty one at the top by the action of the drums, the ropes are disconnected from the wagons by disengaging the riding chains, and both trains are brought to rest by stopping the wheels with sprags.

Each run on the incline occupies about three minutes, so that the speed of the train is at the rate of about 20 miles an hour. In ordinary working 200 wagons are run down per day of twelve hours, conveying 1600 tons of stone. Two men are employed on the drum line and sidings at the top of the incline, and two men at the break-winch, which is situated exactly at the brow of the incline; two men are also required at the bottom of the incline.

These break drums have now been at work about ten months; and two similar drums of 14 feet diameter with wood breaks, that were previously used, have been working about ten years.

Mr. Haswell mentioned that in applying the cast-iron break-blocks it had been expected that, as the bottom half of each break strap exactly balanced the upper half, the two halves would each be quite clear of the drum when the break was taken off; but owing to the small spaces of 1-16th to 1-8th inch that had been left between the blocks lining the strap, to admit of expansion, the bottom half was found to droop in the centre, causing the extremities to bind against the drum on each side. It had therefore been necessary to put in a support underneath the centre of the drums, to sustain the lower halves of the break straps when slacked off the drums; and this had

now been found quite satisfactory in preventing the straps from rubbing against the drums when the breaks were off. These drums had now been working continuously about ten months, and the cast-iron break-blocks showed at present scarcely any perceptible signs of wear. They worked for twelve hours a day, running a train down the incline about every ten minutes when in full work; and, contrary to expectation, there was scarcely any rise of temperature in the metal of the break surfaces at the time of applying the breaks. The previous drums, which had been at work for ten years, had had wrought-iron straps rubbing upon a cleading of elm, and the wear was so rapid that the wood cleading had to be replaced every five weeks at a cost of £20 each time. By the introduction of the cast-iron break surfaces a saving had thus been effected of £200 a year, and the breaks still continued working in satisfactory condition. Another advantage experienced with these drums was that it was found much easier to start the trains than it had been with the previous smaller drums; and he believed this was owing to being able to relieve the cast-iron breaks from the drums more perfectly than had been possible with the old wood breaks.

The PRESIDENT enquired whether the cast-iron break-blocks were lubricated in any way.

Mr. HASWELL replied that they were not lubricated at all, but worked entirely dry; and the drum house was roofed over, so that the rain did not get in to the rubbing surfaces.

The PRESIDENT remarked that the use of break-blocks working dry on the drum without any lubrication appeared to him a decided novelty in the application of break power, and he should certainly have expected the metal surfaces would "seize" under such circumstances, and that the wear would be considerable. He should be glad to know of any other cases where breaks had been worked under such conditions, and what had been the results.

Mr. HASWELL said he believed the idea of using cast iron for break purposes on incline sheaves originated with Mr. Thompson, the engineer of the Pontop and Jarrow colliery railway; and cast-iron break-blocks were extensively used on the wagons of the North Eastern Railway with complete success. Before trying the plan

however on so large a scale as the drums of the Ingleby incline, a cast-iron break had been put up on the Stanley incline, a small self-acting incline on the North Eastern Railway, worked by a wire rope passing half round a sheave at the top, and was found to answer very well. From this experience, coupled with that on the Pontop and Jarrow line, it had then been decided to try a cast-iron break for the Ingleby drums, and the result had proved very satisfactory in all respects. After the breaks had been used for running a train down the incline, the heat of the break surfaces was so inconsiderable that the hand could be held upon them.

Mr. E. Leigh enquired how long the breaks were in operation continuously at each time of lowering a train, and how long they then had to stand before the next train. He should certainly have thought the rubbing surfaces would be apt to become worn and to cut, by working without any lubrication.

Mr. H. A. Fletcher asked what was the speed at which the break surface of the drums revolved.

Mr. Haswell replied that the average working, during the time that there was a full supply of loaded wagons at the top of the incline, was a train down the incline every ten minutes; the run occupied three minutes, leaving the drums then seven minutes to stand at rest. The maximum speed on the incline was about 30 miles an hour, and the highest speed of the break surfaces would consequently be rather greater, their diameter being 20 feet, while that of the drum barrels was 18 feet.

Mr. E. Leigh enquired whether the break surfaces became warmed to any perceptible extent at each time of applying the breaks.

Mr. Haswell replied that they were just very slightly warmed, but not so much at any time as to prevent holding the hand upon them.

Mr. King enquired whether any failure had occurred with the new break drums since they had been put to work, and what had been found to be the cost of working.

Mr. Haswell replied that there had not been any failure of the breaks since they commenced working ten months ago, and they had

not cost anything beyond attendance in working, as no repairs or renewals had been required in any part. From the experience of the working hitherto, he believed the cast-iron break-blocks would probably wear for eight or ten years before they would require to be replaced; the wood blocks of the previous drums on the contrary had required replacing every five weeks, as already stated.

Mr. W. Cochrane mentioned that some time ago, in consequence of the great wear and tear of the elm break-blocks on a colliery winding engine, he had tried cast-iron blocks instead, but had not gone so far as to line the wrought-iron break-strap also with cast iron. The wear however of the cast-iron blocks rubbing against the wrought-iron strap had been so great that he had reverted to the elm blocks. In the present case it appeared the wrought-iron straps were lined with cast-iron break-blocks rubbing upon cast-iron blocks on the drums, and he enquired whether the two rubbing surfaces were turned and bored to fit each other accurately.

Mr. Haswell replied that the break-blocks inside the wrought-iron straps and upon the drums were accurately bored and turned to fit before being put to work. They were all made of the same quality of metal, ordinary cast iron, not chilled or hardened at all.

Mr. J. Taylor enquired whether any information could be given as to the amount of pressure upon the break in working, and whether the speed of the descending train was very much retarded by the break; or whether the absence of wear in the break-blocks might be due to the comparatively small amount of break power actually exerted, if the descending load were allowed to run away without being restrained in any considerable degree by the break, owing to the counterbalancing effect of the ascending train.

Mr. Haswell replied that the pressure on the break surfaces in working could only be roughly estimated, as it depended upon the power exerted by the two men at the hand-winch applying the break; the force of the pull tightening the break straps upon the drums was more than 250 times greater than that exerted by the men at the hand-winch. The top part of the incline was steeper than the bottom, the gradient being 1 in 5 for more than a quarter of a mile at the top of the incline; and consequently when the loaded

train began to descend, the break had to be applied very severely at first; but as it approached the bottom of the incline, where the gradient was less steep, the break had to be released, in order that the loaded train might be able to pull the empty wagons up over the top of the incline. The proper moment for releasing the break was a matter of considerable nicety in working, so as just to enable the empty train to get over the top of the incline without the speed being too great, as there was only a distance of 200 feet for stopping the empty train between the brow of the incline and the drum house.

Mr. C. W. Siemens observed that the accepted theory respecting the mutual relation of mechanical force and heat, according to which the destruction of any amount of force must give rise to an equivalent development of heat, would appear to be hardly borne out in the experience with the cast-iron break now described, if it were the case that the cast-iron break became less heated than the previous wood break in doing the same work. Inasmuch as the cast-iron break was found to wear less than the wood break, it was natural to suppose that the force which had been consumed in destruction of the material of the wood break would in the cast-iron break with the smaller amount of wear be manifested in the form of an increased development of heat. If the cast-iron break did not heat much, he should be inclined to think that there was but little force to be absorbed when distributed over the whole time that the break was applied. He should be glad to know however whether there had been any means of ascertaining the relative amount of heat developed with the present cast-iron break and with the previous one of wood, when doing the same work, estimating in both cases the loss of heat by dispersion. The two cast-iron surfaces of the break would no doubt work upon each other with much less wear than wrought iron upon cast iron, because wrought iron would have a cutting or grinding action upon the cast iron; probably it was the presence of a small quantity of graphite or uncombined carbon in cast iron which enabled two surfaces of that metal to rub together without seizing, by acting as a sort of lubricant between them.

Mr. C. J. Appleby enquired what was the difference in the area of the rubbing surfaces of the cast-iron break, which had already been at work ten months without perceptible wear, and of the previous elm break, which had been worn out in five weeks. He had found from experience with breaks running at high speeds that their durability was mainly a question of the area of the surfaces in contact; and he thought the absence of wear in the present instance might be found to arise from the heat being effectually absorbed by the larger area of the break surfaces.

Mr. E. A. Cowper suggested that in the break drums the large area of the rubbing surfaces might be so great in proportion to the total pressure as to prevent the two metals from taking hold of each other, in which case the only result of working would be that they would get more or less glazed over by the friction, without any wear being produced, the metals not being then absolutely in contact. The fact that these break drums of large diameter were revolving rapidly in the air seemed to him sufficient to account for their surfaces keeping cool in working, owing to the dissipation of the heat generated by the friction; in the case of a revolving air condenser for a steam engine the cooling effect was found sufficient to condense the steam for a 20 horse power engine. Moreover in the instance of the dynamometer breaks employed for testing agricultural engines and machinery, it was found that a break wheel of 5 feet diameter and 8 inches width of strap would keep sufficiently cool of itself for working up to about 4 horse power; but when that power was much exceeded it was necessary to use water for keeping the wheel cool, or to apply a second break wheel in conjunction with the first.

Mr. Haswell said that, as the break drums were made entirely of cast iron throughout, he had no doubt the heat developed by the friction of the break surfaces was immediately dissipated throughout the body of the drums, and was thus prevented from causing more than a slight rise of temperature in the rubbing surfaces themselves. The previous elm breaks on the contrary used to get extremely hot in working, in consequence of the heat being retained so much longer by the wood. The total area of the rubbing surfaces on the present

drums when the breaks were applied was about 160 square feet, which was about 30 square feet more than in the previous wood breaks.

Mr. J. Fletcher remarked that cast iron upon cast iron was now extensively used for bearings in machinery in a variety of cases, where formerly cast iron or wrought iron on brass had been employed and had been found not to stand. In blowing and scutching machines for cotton manufacture, the beater shafts running up to 2000 revolutions per minute used to be made of wrought iron or cast iron running upon wrought iron or brass, but were now always made of cast iron carried in cast iron bearings, a particularly close description of cast iron being specially employed for the purpose. He had also known several instances of heavy vertical shafts supported by a bottom bearing of steel or wrought iron running upon a brass footstep, which had been subject to very rapid wear; but this had been effectually remedied by substituting a cast-iron footstep, and a cast-iron foot to the bottom of the shaft itself. These results seemed to show that the friction of cast iron rubbing upon cast iron, with surfaces of fair extent in proportion to the pressure, was much less than with wrought iron upon cast iron or brass, or with cast iron upon brass; which would account for the absence of any appreciable wear in the cast-iron rubbing surfaces of the break drums now described.

Mr. E. Gilkes mentioned that on the coal wagons of the Stockton and Darlington Railway hollow cast-iron break-blocks had lately been substituted for the wood blocks universally employed previously, and had been found highly successful, the wagon wheels being made of cast iron chilled at the rim. A large number of the wagons on that line were now working with these cast-iron breaks, which proved fully as efficient as the ordinary wood blocks in respect to break power, and had the advantage of wearing very much less rapidly.

Mr. W. Hackney enquired whether the breaks on the drums at the incline had sufficient control over the descending train to be capable of letting it down at a slow speed of only 4 or 5 miles an hour, instead of the usual speed of 20 to 30 miles; and whether the

train could be stopped altogether upon the incline by the breaks. He asked also whether a loaded train had ever been let down the incline by the breaks without the counterbalance of an ascending empty train on the other rope.

Mr. Haswell replied that the descending train with the usual load could be completely controlled by the breaks to any speed desired, and could be stopped anywhere upon the incline by their action; but it had never been attempted to run a loaded train down without bringing a corresponding empty one up.*

Mr. C. Cochrane mentioned that he had tried a break with similar double tightening levers upon a vertical drop for lowering blast-furnace materials, but had found it caused the drop to go by jerks instead of working steadily, and he had been obliged to abandon it in consequence; it was a wrought-iron break strap on a wood-faced wheel, and the levers gave a very powerful bite. Probably the difference in the result of working in that case from the present cast-iron break arose from the circumstance that the motion of the weight had to be completely arrested in a very short distance; and he considered the circumstance of the break drums being employed in the present instance for an incline, instead of for a vertical descent, would prevent the pull ever coming so suddenly upon them as to create a jerk, and would thus go far to account for the successful working of the gear employed.

The President remarked that, from the particulars which had been given respecting the construction and working of the cast-iron break-drums described in the paper, the results obtained with these breaks did not seem to him to contravene the established theory of the mutual convertibility of mechanical force and heat.

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* Since the meeting, an opportunity has occurred for testing the above point, through the accidental breakage of the tail chain connecting the rope to the ascending train of empty wagons, when these had ascended to a distance of about 500 feet from the bottom of the incline, and they consequently ran back down the incline; the descending train of loaded wagons was then safely let down the incline by the control of the break drums alone, and it thus descended nearly the whole length of the incline without the counterbalance of an ascending empty train.

It was clear that in absorbing the same amount of force by the breaks the same amount of heat must be developed, which in the wood break caused the blocks to become greatly heated, on account of the wood itself being so bad a conductor of heat; but in the cast-iron break-drums there was no doubt the heat was rapidly carried away from the rubbing surfaces, which would account for their continuing at a low temperature in working. With regard to the absence of any material wear of the cast-iron break surfaces, he thought the suggestion which had been made was very probably the correct explanation, namely that the extent of the rubbing surfaces was so great in proportion to the pressure upon them as to prevent the metals from coming into sufficiently close contact to produce abrasion. The question was altogether one of practical experience, as the pressure put upon the breaks by the hand-winch must evidently be uncertain. The very interesting particulars which had been given of the employment of cast-iron breaks in the present instance would no doubt prove of great value in connection with other applications of break power.

He proposed a vote of thanks to Mr. Haswell for his paper, which was passed.

The following paper was then read :—

ON A SIMPLE CONSTRUCTION OF STEAM ENGINE GOVERNOR HAVING A CLOSE APPROXIMATION TO PERFECT ACTION.

By Mr. JEREMIAH HEAD, of Middlesbrough.

The irregularity of speed to which all steam engines are liable arises from two principal causes: variation in the pressure of steam supplied, and variation in the amount of resistance to be overcome. Variation of steam pressure may arise from irregular firing, overtaxed boilers, or in the case of waste-heat boilers, from several dampers happening to be closed at once, and from other similar and obvious causes. Variation in resistance occurs when the work to be performed is from its nature intermittent; this variation is at its minimum in such engines as those used for pumping or blowing, and at its maximum in engines such as are attached to saw-mills, rolling mills, grindstones and shears. If an engine readily lags in speed when the resistance increases, its efficiency is lessened just when most required; and if it "runs away" when relieved of work, or when the steam pressure is higher than ordinary, the wear and tear of the machinery connected with it is increased, and at the same time steam is wasted in doing the mischief. These considerations were all fully recognised by Watt, who sought to remedy them by his well-known steam engine governor. Although imperfect and partial in its action, this governor is sufficient for many purposes; and its extreme simplicity has caused it to remain to the present time in more extensive use than any other. It acts on a throttle-valve inserted in the steam-pipe close to the valve-chest, and partly closes the throttle-valve when the normal speed is exceeded, and opens it wider when the speed falls below the ordinary rate. Governors thus exercise their control by varying the area of the aperture through which the steam passes to the cylinder; and a perfect governor would be that which would always accommodate this

variable aperture to suit exactly every variation in resistance to the engine or in pressure of steam.

The governing apparatus however is necessarily limited in its power of control. If the engine be running at a speed below its proper number of revolutions, all that the governor can do is to open the throttle-valve wide; if the engine still lags, want of steam or insufficient diameter of cylinder is then the cause. On the contrary if the engine exceeds its proper number of revolutions, notwithstanding that the throttle-valve be fully closed, then steam must be leaking past in sufficient quantity to overcome whatever resistance may exist, and the remedy is to be found in better fitting of the throttle-valve. So long as the number of revolutions of the engine is absolutely constant, the governor, whatever its construction, will remain unaltered in position; but as it can never be made to anticipate a disturbance, but rather its operation must be the effect of a disturbance, the existence of departures from the normal speed is a necessary condition of its action. Hence no governor can keep an engine to an absolutely uniform rate of revolution under variations of pressure or resistance.

But though absolute perfection is unattainable, it may be approached to almost any degree of nearness; and the merit of any governor depends on the smallness of the amount of variation which it will permit, above and below the normal speed, before exercising its full control in opening or closing the throttle-valve. Thus supposing that an engine liable to extreme variations in resistance be arranged for a speed of 40 revolutions per minute; then if at 41 the governor were thrown into a state of uneasiness and rose further and further until the throttle-valve were almost closed, rather than permit a further increase or even a continuation of that speed; and if at 39 revolutions it manifested a similar restlessness, and fell lower and lower until the valve were fully open, rather than permit a further decrease or a continuation of the same speed; then such a governor might be considered as practically perfect. But supposing another governor attached to a similar engine were to rise only a little at 41 revolutions, and stop contented there, and at 42 to rise yet a little higher, and there to remain, and so on for each increment of

speed until 50 revolutions were necessary to enable it to keep the valve fully closed, or on the other hand 30 to keep it fully open; then it is evident that the second governor, permitting a variation of 10 revolutions per minute each way, above and below the normal speed, before exercising its maximum control, would be inferior to the first one, which permitted a variation of only one revolution each way. The second governor might however be good enough for many ordinary operations, and much better than none. The object of the present paper is to show that, while the ordinary Watt governor as at present in general use is of the nature of that last named, allowing a serious change of speed before it effects the required regulation in the supply of steam to the engine, yet it may, without any material increase of complexity or expense, be so modified in construction as to approach very nearly to the standard of theoretical perfection.

The ordinary governor consists of an upright spindle, driven by the engine and therefore partaking of any irregularity in its speed, and carrying two arms, one on either side, attached to the top by a joint, and terminating in heavy balls. The balls hang close to the spindle when at rest, but when in motion are projected outwards by the centrifugal force of rotation. The suspending arms are free to rise with the balls, and are connected by rods and levers to the throttle-valve, so that when in their lowest position the valve is fully open, and when at the highest it is nearly or entirely closed. The arms and balls are in duplicate simply for the purpose of balancing each other; and the whole forms a pair of what have been termed conical pendulums.

The time of rotation of a conical pendulum depends solely on the height of the cone described by the suspending arm and ball; and is the same as the time of oscillation of an ordinary pendulum having the same length as the vertical height of this cone measured from its apex to the centre of the ball. The centrifugal force which maintains the expanded position of the ball is directly proportionate to the radius of the circle described by the ball, and to the square of the angular velocity of rotation or the number of revolutions per

minute; and in the particular case therefore when the number of revolutions is uniform, the centrifugal force is directly proportionate to the radius in all positions of the ball.

The proportion between the weight of the ball and the horizontal force required for supporting it at any angle is also the proportion between the height of the cone described by the suspending arm and the radius of the circle described by the ball. When the governor balls are made to rise in the curve of a parabola, the height of this cone is always the same, whatever may be the increase of length of the radius. This is owing to the property of the parabola, that the points of intersection with the axis, by a line drawn at right angles to the curve and by another drawn at right angles to the axis from the same point in the curve, are always at the same distance apart, whatever may be the position of the point in the curve from which the two lines are drawn; in other words, the length of the subnormal is constant for every point of the curve. As therefore the horizontal force required to support the suspending arm and ball at any angle is directly proportionate to the length of radius of the described circle, and as the centrifugal force which supplies this required power is also in this case directly proportionate to the same radius, they will consequently be in equilibrium in every position. Hence whatever may be the position of the balls, whether low down or high up, when moving in the curve of a parabola, they will retain that position and will have no tendency to change it, provided only the number of revolutions per minute is kept unchanged. Opening or closing of the throttle-valve to any extent can accordingly be effected and maintained, without necessitating any alteration in the speed of the engine.

This perfect action however can only be obtained when the balls rise in the curve of a parabola. But when they are hung from a point in the axis, and move in an arc of a circle, as in the ordinary governor, the height of the cone described by the suspending arms diminishes as the balls rise; and at the same time that the height of cone diminishes, the horizontal or centrifugal force requisite for supporting the balls increases; consequently the centrifugal force is

now required to increase more rapidly than in the simple ratio of the radius. This required increase can therefore be obtained only by increasing the number of revolutions per minute; and the result is that with the ordinary governor a change in time of revolution is necessary for each change in position of the balls. When therefore the resistance to the engine falls off, say to one half, and the throttle-valve is partially closed by the rise of the balls, the new position can be maintained only by a permanent increase in the running speed of the engine.

With the parabolic governor on the contrary no such change of speed is required, however great may be the change in the resistance to the engine; the centrifugal force always alters with each change of position of the balls; in exactly the same proportion as the change in the force required to support the balls in their new position. The effect of any diminution of the resistance to the engine is a momentary increase in its speed, and a corresponding increase in the centrifugal force acting on the balls, beyond the amount required for maintaining them in their position. They consequently rise, closing the throttle-valve as they ascend, until the temporary acceleration of the engine is checked, and it is brought back to its original speed. The governor balls then settle themselves in the new position suited to the altered degree of opening of the throttle-valve, keeping the engine steadily at its original standard speed. In the same way, upon any increase of resistance to the engine, the opposite action of a momentary reduction in its speed takes place, causing a corresponding adjustment of the throttle-valve to a wider opening, by the governor balls settling into a lower position.

It has to be noticed that, in the form in which the governor was made by Watt, the actual extent of variation of speed was reduced to a very small amount. In Fig. 1, Plate 60, is shown a diagram of the original governor made by him, and now preserved in the South Kensington Museum. By choosing a height of cone which corresponded with a slow speed, and making the angle between the arms and the axis small at their lowest position, and limiting the change of angle to the smallest amount practicable, and also by the ingenious method of actuating the sliding-piece at the top, a sufficient

rise and fall of the latter was secured with an extremely small change of height in the described cone. Thus this governor would begin to rise at 36 revolutions, and would reach its maximum height at 38, corresponding to a variation of only $5\frac{1}{2}$ per cent. in the speed of the engine. No doubt a short compact governor is more commodious and cheaper, and a large wide-spreading one is quite unsuitable for small quick-running engines; and it is also convenient to secure each suspending arm to a separate joint on the same side of the spindle as the arm itself, as in the construction ordinarily employed; but these modifications have seriously impaired the efficiency of the original Watt governor.

In Fig. 3, Plate 61, is shown a sketch of the first parabolic governor introduced into this country at the 1851 Exhibition, by an exhibitor from Vienna, where it had been some years at work. The balls were suspended by links to rollers, which travelled upon arms A A branching out from a vertical spindle, and bent to such a curve as would cause the centres of the balls to describe a parabola in rising and falling. A governor on this principle was adopted in a pair of compound engines, designed by the writer at Messrs. Robert Stephenson and Co.'s works a few years afterwards, for driving Messrs. Pease and Co.'s Woollen Mills at Darlington. The spinning of woollen yarn, especially the finer numbers, is an operation which requires great regularity in the motive power, otherwise the threads are continually breaking; and this governor was found on trial to answer almost exactly to the calculations which had been made respecting it. The balls rose to the very top or fell to the very bottom of their path with the slightest variations of speed; and had there been no momentum in the moving parts in an upward or downward direction, the action of the governor would have been perfect. But it was rendered completely useless by the continued disturbance of the throttle-valve, after the proper position had been reached, which resulted from the balls having "way" on them, so that they were perpetually running up too high and bringing the engine almost to a stand-still, and then running down too low and letting it "run away."

This difficulty was then obviated by a very simple expedient, namely by attaching to the sliding-piece of the governor an air cylinder or cataract B, as shown in Fig. 4. In rising or falling, the balls were made to suck or force air into or out of a small adjustable aperture in the top of this cylinder; and in this way no velocity or momentum in a vertical direction was allowed to accumulate. The parabolic governor so modified was perfectly successful, and after fifteen years' working is still in operation at Messrs. Pease and Co.'s Woollen Mills, Darlington. There are also several examples of this governor at Messrs. R. Stephenson and Co.'s works, Newcastle; and one at Messrs. Annandale and Sons' paper mills, Shotley Bridge.

But there are some disadvantages connected with the parabolic governor even in this improved form; it is a little complicated, and more costly than the ordinary one, and the surfaces of the rollers and the paths upon which they travel are liable to wear into inequalities of level. These considerations have suggested the idea of constructing a simpler governor, by sacrificing a small portion of the perfection obtained by adhering rigidly to the true parabola. In the diagram shown in Fig. 7, Plate 63, the curve shown by the strong full line is a true parabola; and although no arc of a circle can exactly coincide with any portion of a parabola, because the latter is always altering its curvature, yet it will be seen that one may be found, which within a certain limit of length approximates very nearly to it, as shown by the dotted circular arc. If then the ball is hung from L, the centre from which such a circular arc is described, a governor will be obtained that is nearly parabolic, and yet has all the simplicity of the ordinary governor. It will be seen that the centres of suspension are here situated each on the side of the vertical spindle *opposite* to the suspended ball, the arms thus being crossed.

The mode of laying down this approximate parabolic governor is as follows. The lowest position of the ball B, Fig. 7, is first fixed according to convenience, and the height of the cone D F is determined according to the number of revolutions intended, as shown in the

following table giving the results obtained by calculation. The line B H is then drawn at right angles to B F, and the bisection of D H at A gives the apex of the parabolic curve. The total rise D E of the ball is then fixed at the amount considered desirable, and the proportion of E C to D B is made the same as that of $\sqrt{EA}$ to $\sqrt{DA}$. A point C is thus found in the parabolic curve, as the ordinate E C of a parabola is proportionate to the square root of the corresponding abscissa E A; and in a similar way any number of other intermediate points in the parabola may be obtained. It only remains to find by trial a centre L, from which a circular arc may be drawn coinciding as nearly as possible with that portion of the parabola between B and C.

The table for ascertaining the number of revolutions corresponding to any height of cone from 6 to 36 inches is calculated from the data that the number of revolutions is inversely proportionate to the square root of the height of the cone; and that when the latter is 39·1393 inches, or the length of the seconds' pendulum, the time of revolution is equal to a double oscillation thereof, or two seconds. Whence the following formulæ are easily constructed, n being the number of revolutions per minute, and h the height of cone in inches:—

$$n = \sqrt{\frac{30^2 \times 39{\cdot}1393}{h}} = \sqrt{\frac{35225}{h}}$$

$$h = \frac{30^2 \times 39{\cdot}1393}{n^2} = \frac{35225}{n^2}$$

TABLE.

Height of cone in ins.	6	7	8	9	10	11	12	13	14	15	16	17	18
No. of revs. per min.	77	71	67	63	59	56	54	52	50	48	46	45	44
Height of cone in ins.	19	20	21	22	23	24	26	28	30	32	34	36	
No. of revs. per min.	43	42	41	40	39	38	37	36	35	34	33	32	

Some allowance should be made for the weight of the sliding-piece and its connections, unless these are counterbalanced; as the tendency of such dead weights is to necessitate a higher speed than given in the table, before the balls will rise.

In Fig. 5, Plate 62, is shown the approximate parabolic governor that is attached to a large single-cylinder horizontal engine driving two plate-mills at the Newport Rolling Mills, Middlesbrough. In this form of governor the air cataract has been found unnecessary; but a spiral spring C is placed upon the spindle, and acts in a somewhat similar manner. It is under no compression and therefore inoperative when the balls are at their lowest position, but offers a slight and increasing obstruction to them by compression in rising, obliging them to wait an instant, to ascertain, as it were, whether they have made an impression, and thus prevents a blind rush upwards. In falling, the spring urges them to start slightly in anticipation of a decrease of speed; and in their downward progress, as they find less and less help from it, they tarry, refusing, as it were, to hurry on further than may be necessary. Of course the tendency of the spring would be to permit a trifling variation of speed, rather than the serious alternations previously described in the action of a truly parabolic governor, were it not for another circumstance. On examination of the heights of the described cones at the highest and lowest positions of the balls, after the radii of the approximately coinciding circular arc have been drawn, as shown in Fig. 7 by the dotted lines B L and C L, it will be found that these heights are no longer perfectly equal. The height of the uppermost cone has now become a little greater than that of the lowest one, indicating that the balls will be quiescent in their highest position at a somewhat lower speed than in their lowest. This circumstance, tending to produce or aggravate the alternations in the action of the governor, can be entirely neutralised by the spring, provided its resisting power be made to correspond, as it has the opposite effect; and thus almost absolute perfection may be attained.

It has been found advisable in some cases to cause the lever actuating the throttle-valve spindle to beat upon an adjusting screw, so set as to prevent the entire closing of the valve; there is evidently no occasion ever to contract the admission aperture below what is necessary to drive the engine nearly up to its proper speed, when running light, with the steam at maximum pressure; and the set-screw must be adjusted accordingly.

With regard to the actual amount of variation permitted by this governor, above and below the normal speed, it is difficult to estimate it otherwise than roughly. The proper speed of the engine in this case is 40 revolutions per minute, and when nothing is passing through the rolls, the balls habitually remain up at their highest position, provided always the steam is at its ordinary pressure. When plates are being rolled, the effect upon the governor is immediately observable; and when they become so much extended as to offer sensibly increased resistance to the engine power, the balls fall right down every time a plate goes through, but are up again before the time for re-entering returns. The writer has counted the revolutions of the engine when the balls were in either of their extreme positions, without being able to detect any difference of speed. But the uniformity of the noise of the wheelwork is to the practised ear quite sufficient to prove that the number of revolutions is practically constant, whether iron is being rolled or not. There are ten of these approximate parabolic governors at work at the Newport Rolling Mills, one of them regulating a roll-turning lathe driven by a small separate engine; and whether the tool is cutting or not, or whether the cut is heavy or light, the governor keeps the speed uniform. Others are attached to heavy shears, each with a separate engine; and in these cases the rapid turning on of the steam when a heavy cut is being made, and the equally rapid throttling of it when the cut is accomplished, are very remarkable.

At Messrs. Stephenson's works, Newcastle, a parabolic governor is attached to a varying expansion gear having two slide-valves, one on the back of the other, and the governor by means of a link actuates the cut-off slide; the engine drives a circular saw only, which certainly affords a severe test. Nevertheless the governor does its duty perfectly, cutting off as late as possible when the engine lags in speed, and as early as possible when serious resistance has ceased. The ease and quietness with which the changes of expansion are accomplished are remarkable. In the iron-making district of Cleveland, where steam is mostly raised from the waste heat of fuel used primarily for other purposes, saving of coal is accounted of less importance than simplicity of construction;

otherwise the writer sees no reason why the expansion combination should not always be preferred to a simple throttle-valve.

The error in action of the ordinary governor becomes increased where the arms are hung from two separate points of suspension, away from the spindle, and each on the *same* side as its suspended ball, as shown in Fig. 2, Plate 60. Then the fault of variability in height of cone becomes aggravated, the apex of the cone being actually lowered, instead of remaining stationary as the balls rise; and the cone A B C curtailed at both ends becomes at last that represented by D E F. The variation of speed with such a governor is proportionately increased, and in extreme cases hardly any benefit can be derived. In the governor shown in Fig. 2, which is by no means an uncommon example, the balls would begin to rise at about 28 revolutions, and would require 46 to reach the position shown by the dotted lines; and the extreme variation of the engine would therefore amount to 47 per cent. of its mean speed.

Where engines are regulated by the ordinary governor, the speed is usually modified in part by the attendant at the shut-off valve, which is seldom allowed to remain fully open, if there be abundant steam pressure, because the governor cannot be trusted to control unaided. On the other hand, engines properly fitted with the parabolic or approximate parabolic governor may safely work with the shut-off valve fully open, and should always be permitted to work so; otherwise when a serious increase of resistance takes place, and the balls fall to their lowest position, the steam is still obstructed before reaching the throttle-valve, and the time occupied in recovering speed is proportionately long. But it is difficult to overcome the prejudice of engine-men in this respect; from long habit they are usually afraid to open the shut-off valve fully, and in such cases the governor is prevented from doing its duty.

Mr. Head exhibited a working model for the purpose of illustrating the action of the approximate parabolic governor with crossed arms, described in the paper, as compared with the best form of the Watt governor, and with the commonest or worst form. The model contained one of each of these three constructions of governor, all of which were geared together so as to revolve at the same speed; and the range of vertical movement of the sliding collar for working the throttle-valve was the same in each governor. On causing them to revolve, it was seen that a very slight increase of speed, beyond the normal rate for which they were all adjusted, caused the balls of the crossed-arm governor to rise quickly into their highest position, while those of the two other governors hardly changed their position at all. A further increase of speed was necessary to raise into their highest position the balls of the Watt governor, having long arms centred upon a single pin in the axis of the vertical spindle; and a considerably greater speed had to be attained, before reaching the highest position of the balls in the common governor, in which each ball was suspended by a short arm from a separate centre pin on the same side of the vertical spindle as the ball itself. On reducing the speed again, the balls of the common governor were the first to fall; next those of the Watt governor; and last those of the improved governor with crossed arms, which did not begin to fall until the speed of rotation had been reduced very nearly to the normal rate, when they fell quickly to the lowest position, reaching it simultaneously with the two other governors. The model thus showed the very sensitive character of the crossed-arm governor, in which a difference of speed so slight as to be scarcely appreciable by the eye was sufficient to cause the balls to rise or fall quickly through their entire range of motion.

Mr. L. Olrick said he had had occasion some years ago to apply a number of governors to marine engines, in which case, owing to the motion of the ship, a different kind of governor was required from that suitable for land engines. For the latter he had found the differential governor of Mr. Siemens was the best, because it was nearly theoretically correct; while the best governor for marine

engines was Silver's balanced four-ball governor, which had only two arms joined in the centre, but one ball on each of the four ends of the two arms. In Mr. Siemens' differential governor, advantage was taken of the inertia of the heavy revolving ball to resist any sudden change in speed, and thus allow the spindle to turn in advance of the heavy ball or be retarded, and by its direct connection with the throttle-valve to close or open the latter either wholly or partially according to circumstances, thus preventing any increase or decrease of velocity of the engine. For marine governors however it was necessary to have a balanced arrangement, in order that the pendulum action might not be affected by the rolling of the ship; and from his experience with marine governors he was of opinion that the best governor for marine purposes would be Silver's balanced four-ball governor with the differential motion of Mr. Siemens' governor. The improvement in this consisted in introducing a loose pulley on the spindle, by which any sudden start of the engine was transferred directly and instantaneously through bevil wheels to the throttle-valve; and thus the inertia of the balls, which otherwise would cause the gearing to break or the driving band to slip, became instrumental in shutting the valve, in combination with the centrifugal force of the balls; the reopening of the valve was effected by the spiral spring. A number of governors upon this plan which he had fitted into ships had proved excellent marine-engine governors, and had now continued for a number of years in use with complete success. Another construction of governor that would be suitable for marine engines was the one having a revolving flywheel, the speed of the wheel being regulated by its own inertia together with the resistance of the air acting against a number of vanes fixed upon its circumference; such a governor however, although also acting on the differential principle, could not be expected to be so sensitive as the four-ball governor.

In the fitting up of the ordinary two-ball governors, one point that appeared to him decidedly objectionable was the addition of a guide for the arms of the balls to work in. The consequence of this addition was that, as soon as the engine began to depart from the proper speed, the first effect was to press the governor arms hard

against one side of the guide; and the friction thus occasioned had then to be overcome by the balls before they could rise or fall to act upon the throttle-valve, thereby allowing the engine time to run away before it could be checked. He had also found that inferior workmanship in the fitting of the different pins and joints was frequently a cause that impeded the proper working of the common governors, and rendered them even worse in action than they were already in principle. Having previously met with many governors that were theoretically good but did not prove thoroughly satisfactory in practice, he had felt some doubt as to the practical value of the crossed-arm governor described in the paper now read; but having had an opportunity of seeing the governor at work at the rolling mills of Messrs. Fox Head and Co. in Middlesbrough, he had been much pleased to find it almost perfect in action, having been unable to detect any difference of speed from the sound of the machinery during the process of rolling. There was also a pair of shears that was worked by the engine controlled by this governor; and he had observed that every time a cut was made in the shears, the governor turned the steam full on at the instant of commencing the cut, and shut it off again instantaneously upon the cut being completed. These results showed that the governor might be considered practically perfect in its action.

Mr. C. W. Siemens remarked there could be no doubt that by the plan of crossing the suspending arms of the governor, so as to cause the balls to expand in a parabolic curve within certain limits, as described in the paper, a real chronometric action was obtained; but such an action would not be practically applicable to regulate the speed of a steam engine, because, as had been explained, there would be no tendency for the balls to stop in their movement if the governor were perfectly chronometric, but they would fly at once from one extremity of their range to the other under the slightest alternations of speed. The common governor was the one that was least affected by change of speed, and required the greatest amount of change to bring it into action; but it had the advantage of not allowing the engine to "hunt" or beat about between the extremes of speed before settling down to the proper rate; it was thus a safe

governor in this respect, though a bad one in others. The original invention of Watt, which had also this advantage and moreover allowed of only a slight variation in speed, occupied a sort of mean position between the common governor and a parabolic one, and was therefore the best practical governor hitherto applied; and the same might now be said of the modified construction of the crossed-arm governor, in which the spiral spring was added, as described in the paper. The addition of the spiral spring however did away with the true chronometric character of the governor, because the spring acted in conjunction with gravity to depress the balls, without being influenced by the cross suspension; and therefore a greater increase of speed was still required to raise the balls, and the governor was thus rendered a practical one, instead of being a mere theoretical abstraction as would be the case without the spring. A further advantage of the spring, when aiding gravity to depress the balls, was that the centrifugal force on the balls was thereby increased; if for instance a speed of 40 revolutions per minute was sufficient to maintain the balls at their mean angle when no spring was used, and if with the spring 60 revolutions per minute were requisite to keep them in the same position, the centrifugal force residing in the balls in these two cases would be in the proportion of the square of 40 to the square of 60, or as 4 to 9, and the regulating power for a given variation of speed would be increased in the same proportion. A smaller relative variation in speed therefore, in the governor provided with the spring, would be sufficient for enabling the balls to overcome the constant resistance of the valve-levers and valve; and this he believed to be one of the reasons why the crossed-arm governor described in the paper acted so well. The only kind of governor that was capable of acting instantly upon the throttle-valve at the moment of the change of speed was the differential governor; but short of the differential governor the arrangement of the crossed-arm governor with spiral spring appeared to him a very useful and valuable one.

Mr. Head observed that the addition of the light spiral spring in the crossed-arm governor had not been made with the view of increasing the power of the balls to act upon the throttle-valve at any change of speed, but simply for the purpose of checking an

undue movement of the balls in rising. In the lowest position of the balls, the spring was under no compression and exerted no pressure at all; but the rise of the balls was met by a slight and gradually increasing resistance from compression of the spring, which prevented them from rising too fast. It was true that to the extent to which the spring acted effectively it destroyed the chronometric character of the governor; but the question was simply one of degree, as to the advantage to be gained by a more or less close approximation to perfect chronometric action; and in the case of the rolling-mill engines at his own works, which were controlled by one of these governors, he did not think any variation in the speed of the machinery could be detected.

Mr. Olrick enquired whether any of these governors had been applied direct to move an expansion valve, instead of acting upon the throttle-valve in the ordinary manner.

Mr. Head replied that one of the governors was applied to work an expansion valve in an engine at Messrs. Stephenson's works at Newcastle.

Mr. W. Thompson mentioned that he had one of the crossed-arm governors in use on the engines driving the machinery at his works in Newcastle; the regular speed was 60 revolutions per minute, and he had never been able to count 61, whether the engines were driving one or more machines at the time.

The President proposed a vote of thanks to Mr. Head for his paper, which was passed.

The following paper was then read:—

ON STEAM BOILERS WITH SMALL WATER-SPACE, AND ROOTS' TUBE BOILER.

By Mr. CHARLES COCHRANE, of Middlesbrough.

Boilers designed with the twofold object of small water-space and small areas exposed to pressure occupied much attention when high-pressure steam was first used, and have now again come into favour from the proved economy of higher pressures of steam than are safe with ordinary boilers; they therefore deserve careful consideration. The objects aimed at in boilers of this class are good: on the one hand to remove danger by avoiding large accumulations of highly heated water, each cubic foot of which, in a boiler working at 60 lbs. pressure, contains as much explosive energy as one pound of gunpowder; and on the other hand to make the parts so small as to avoid severe strains on the material of construction. The chief difficulty hitherto felt with such boilers appears to be that they are less regular in their supply of steam, as they do not contain the dangerous accumulation of water existing in ordinary boilers, which serves also as a store of power, giving out steam copiously whenever the pressure is diminished by any lowering of the fire or by any extra demand for steam. Another difficulty has been that, as all the water is evaporated within such a small space, the deposit left from it tends to fill up that space rapidly, or to cause a thick crust which retards evaporation. A serious practical difficulty has been the great number of separate parts in boilers with small water-spaces, and the consequent numerous joints that have to be kept tight, and also to be taken apart for cleaning the boiler; and the latter operation not only requires much skilled labour, but in many cases is rendered difficult owing to the screw threads having become worn out, involving leakage and corrosion.

Some of the earliest of the high-pressure boilers were made of cast-iron pipes of small diameter, as in the early Woolf boiler illustrated in Fig. 1, Plate 64, which consisted of a layer of horizontal cast-iron pipes, 12 inches diameter, exposed to the direct heat of the fire externally, and connected above to a larger pipe, and this again to a steam receiver. In this boiler the principle of small water-space and small areas exposed to pressure was well carried out; but the material and the construction of the joints were not suitable for durability and safety.

When light and quick steam generators were required for the introduction of locomotives on common roads, some ingenious forms of tube boilers were designed, such as Hancock's, shown in Fig. 2, Plate 64, which consisted of a set of vertical wrought-iron tubes $4\frac{1}{2}$ inches diameter, arranged in parallel rows, each tube having a small flue-tube 2 inches diameter passing through it for increasing the heating surface, as shown in Figs. 3 and 4. The tubes were connected together by small feed and steam pipes, and communicated with a steam receiver on the top; and the whole was enclosed in an external iron casing.

Another arrangement for a similar purpose was Ogle's boiler, Fig. 5, Plate 64, consisting of a cluster of vertical tubes 4 inches diameter, connected at top and bottom to two rectangular chambers, the lower one for water and the upper one a steam receiver; and each tube had a small flue-tube $1\frac{1}{2}$ inch diameter passing through it, which served also to stay the outer plates of the top and bottom chambers, as shown in Fig. 6.

Both these plans of boiler were used with considerable success; and attempts were also made to use a set of thin flat chambers, as in Hancock's boiler, Fig. 7, Plate 64, connected together at top and bottom by a single steam pipe and feed pipe, as shown in Fig. 8. The flat chambers however were found to depend for strength too much upon stays, and various plans of corrugated and bulged plates were tried with indifferent success.

A striking novelty which was used in some steamboats was James' boiler, Fig. 9, Plate 65, composed of a series of annular cast-iron tubes, about 6 inches square in section and 3 feet diameter inside,

which were placed side by side, and connected together by a water pipe at the bottom and a steam pipe at the top, as shown in Fig. 10; the cast-iron tubes thus formed a cylindrical space, within which the fire was placed, the whole being enclosed within a metal case.

When it was found that vessels of large diameter could be made of rivetted plates and capable of standing high pressures, the early small water-space boilers fell into disfavour, and the few then designed were little used. It has only been recently that the principle of small water-space boilers has been revived, in consequence of the rapidly growing demand for higher pressures of steam than are admissible with the ordinary large boilers; and the following examples will serve to illustrate briefly the very ingenious principles of construction that have been brought out for this purpose.

The first to be referred to is the very high pressure boiler of Perkins, shown in Figs. 11 and 12, Plate 65. This boiler consists entirely of small wrought-iron tubes of only $2\frac{1}{4}$ inches internal diameter, which are connected together in successive horizontal layers, and are all exposed to the direct heat of the fire, the water being fed in at the bottom; and the steam carried off at the top. A special feature is that all the horizontal tubes are connected together by smaller wrought-iron vertical tubes with screwed gas-pipe joints; the strength of these joints and the very small diameter of the tubes allow of using very exceptionally high pressures of 200 lbs. per inch and upwards. Boilers on this plan continue in use at the present time with good effect. (See Proceedings Inst. M. E. 1861 page 94.)

Combinations of small wrought-iron tubes have been employed in various ways for boilers, and an example of one arrangement is Belleville's boiler, shown in Figs. 13 and 14, Plate 65. This consists of a series of parallel horizontal tubes about 4 inches diameter inside, each of which is carried up from the bottom to the top of the boiler, by a succession of bends overlying one another; and each thus forms a separate course from the feed pipe running along the bottom to the steam pipe along the top.

Another arrangement is the Jordan boiler, shown in Figs. 15 and 16, Plate 66, consisting of rows of vertical tubes $8\frac{1}{2}$ inches internal diameter, connected together in each row at top and bottom.

A very ingenious boiler on an entirely different principle of construction is the Harrison boiler, shown in Figs. 17 and 18, Plate 66, which is composed entirely of a number of small hollow cast-iron balls of 8 inches external diameter, cast in sets of four balls, and arranged in parallel inclined lines; the balls in each line are in communication throughout, and are strung together upon a long bolt that is screwed up at each end; the several lines of balls communicate together in vertical rows, as shown in Fig. 18. This plan of boiler, which was an American invention, is in considerable use there; but it has not proved successful in this country, and has not continued in use, owing to the trouble caused by the liability of the cast-iron balls to split in working, and the delay of removing and replacing them, and also in consequence of the difficulty of keeping all the numerous joints steam-tight. The castings are all made with faced joints, finished to an exact gauge and fitted together metal to metal; and the very accurate adjustment that had consequently to be maintained throughout for keeping all the numerous joints steam-tight was liable to be disturbed by irregular expansion occurring in working the boiler. The shape of the balls was also found objectionable, in consequence of their forming a succession of pockets throughout the water space, and thus serving for the retention of deposit. (See Proceedings Inst. M. E. 1864 page 61.)

Another novel principle of boiler, also of American invention, is the Benson boiler, shown in Figs. 19 and 20, Plate 66, which consists of a number of small horizontal parallel tubes $1\frac{1}{2}$ inch inside diameter, connected by bends at the ends, so as to form in each vertical row a single continuous zigzag tube from the bottom to the top; the whole of the rows are coupled together by a single horizontal tube at bottom and at top. The special feature of this boiler is that a continuous artificial circulation of the whole of the water is maintained by means of a donkey pump, which is continually drawing off the water from the top and returning it to the bottom

of the boiler. An external cylindrical vessel about 3 feet diameter, extending the whole height of the boiler and communicating with the top and bottom connecting pipes, is employed as a receiver and separator for aiding in obtaining dry steam. This plan of boiler involves the objection of depending upon a mechanical appliance for producing circulation of the water, as the water spaces in the tubes are too small for working otherwise without risk of becoming choked with deposit; but it has proved successful, and continues at work in this country to a limited extent. (See Proceedings Inst. M. E. 1861 page 30.)

The demand for steam fire-engines led to the production of some very rapid steam generators, having small vertical tubes hanging down into the fire with their lower ends closed. These boilers have a reservoir of water of some extent externally, but by filling up the space with hollow copper vessels suspended inside the tubes the quantity of water contained in the boiler is reduced to a small amount, in order to allow of getting up steam in a very short time. A difficulty was found however with these pendent water tubes, from their soon becoming choked up with deposit and getting burnt; and also the steam was sometimes generated so rapidly in the tubes as to blow the water out, causing the tubes to be overheated and consequently to get out of shape and become leaky. This difficulty was then overcome by obtaining a continuous circulation of water in the tubes, by the introduction of small internal circulating tubes, through which a down current of cooler water is secured from the reservoir above, undisturbed by the rising steam in the upward current of heated water in the outer annular space.

The circulating action was rendered more certain by the funnel-shaped top of the internal Field tube shown in Fig. 22, Plate 67. In the Field boiler, Fig. 21, a number of rows of pendent tubes about 4 inches diameter, containing circulating tubes about 2 inches diameter, are suspended from a series of parallel tubes, placed inclined for collecting deposit, and connected at the ends to larger water and steam tubes. This plan has also been used to a considerable extent as an addition to ordinary large water-space boilers, for increasing their heating surface.

In the Howard boiler, Fig. 23, Plate 67, which has been applied to a considerable extent both to stationary and portable engines, a series of horizontal wrought-iron tubes of ▽ section are arranged longitudinally in a layer over the fire, and on each of them stands a row of vertical wrought-iron tubes, each containing an internal circulating tube, as shown in Figs. 24 and 25. The vertical tubes are about 8 inches diameter, and are screwed into the flat side of the bottom horizontal tubes; they are closed at the top with a solid welded end, into which a short piece of gas pipe is screwed, connecting each row of tubes to a horizontal steam pipe above.

In the Allen boiler, shown in Figs. 26 and 27, Plate 67, which is in use in America, a series of rows of pendent inclined tubes about 5 inches diameter are used, closed at the bottom, and all exposed to the fire. The tubes in each row are connected at the top by larger horizontal tubes, which communicate with a steam receiver above; the inclined tubes are filled with water, which also half fills the horizontal tubes. There are not any circulating tubes within the pendent tubes, but these are placed inclined with the object of obtaining a circulation by the feed water descending on one side and the steam ascending on the other side.

A class of boilers has been made in which the water space is reduced by the introduction of a large steam space in the interior of the water, or by having a series of concentric chambers of water and steam alternately; but as in all such cases there is still a single external cylindrical shell of large size, these boilers are similar to ordinary large boilers in their exposure to risk of explosion from high pressure acting upon large extent of surface.

In the following Table a comparison is given of the water contents in several constructions of boiler, in relation to their respective heating surfaces: as the basis for the comparison an ordinary Cornish boiler having 500 square feet of heating surface is taken, the dimensions being about 30 feet length and $6\frac{1}{2}$ feet diameter; and the same extent of heating surface, 500 square feet, is assumed in each of the other boilers, for the purpose of uniform comparison.

Proportion of Water Contents to Heating Surface in various classes of Boilers.

Class of Boiler.	Heating Surface.	Water Contents.	Space occupied.	Approximate dimensions.	
	Square ft.	Cubic ft.	Cubic ft.	No. of boilers.	Size. Ft. Ft. Ft.
Chimney	500	1120	3,000	4	25 × 5, 2½ tube
Balloon	500	1005	10,000	1	18 × 18
Furnace	500	909	7,680	1	25 × 9½
Cylinder	500	775	4,000	1	80 × 4½
Lancashire	500	404	2,700	1	28 × 6½, 2½ tubes
Cornish	500	375	2,900	1	30 × 6½, 4 tube
Locomotive	500	70	360	1	10 × 4
Tube Boilers (average)	500	40	760	1	60 tubes or more
Steam Fire Engines .	500	27	250	5	5 × 2

From this table it will be seen that whilst the Cornish and Lancashire boilers have about 400 cubic feet of water for the 500 square feet of heating surface, the Furnace, Balloon, and Chimney boilers have more than double the proportion of water contents, but in the Tube boilers the proportion amounts to only one-tenth or 40 cubic feet of water.

After considering the subject with a view to making a trial at the Ormesby Iron Works of this principle of boiler—namely small water-space combined with small surface for pressure—the writer determined upon adopting Root's boiler, shown in Figs. 28 and 29, Plate 68; and two of these boilers have now been at work there for about three quarters of a year. This boiler is an American invention, and the following is a description of its construction, with the particulars of the results of working, and of experiments made by the writer upon its evaporative duty.

The boiler consists entirely of a series of similar wrought-iron tubes A A, Figs. 28 and 29, arranged in parallel layers with clear spaces between all the tubes, and the tubes in each layer are over the spaces in the layer below. The tubes are placed at an inclination of 1 in 3, rising from the back towards the front, as shown in Fig. 28; and are connected together at both ends by caps C C, which couple

each tube both to the one below and the one above, so as to form a continuous communication in a zigzag direction between all the tubes in each successive vertical row. The furnace chamber B is directly below the boiler, and extends to the same width and length; and the flame and heated gases pass up between the tubes, and escape at a flue F at the top, which passes down outside to the chimney flue. The heated gases are made to traverse the length of the boiler three times in passing from the furnace to the exit flue, by three light cast-iron deflecting plates D, resting upon the tubes and closing the passage between them for about three quarters of their length from either end alternately.

The tubes are wrought-iron lap-welded tubes, 4 inches external diameter in the lower rows and 5 inches in the upper rows, as shown in Figs. 32 and 35, and 9 feet long. They are screwed at each end into a square cast-iron head H, Figs. 32 to 36, Plates 70 and 71, and these heads are all planed on the four sides, and finished to a uniform gauge of $7\frac{1}{2}$ inches width and 8 inches height; they are then fitted close together metal to metal in the boiler, so as themselves to form the front and back walls of the boiler setting, as shown in Figs. 29 and 31. Each of the tube heads has two circular openings on the outer face, one above the other, Fig. 36; and oblique hollow cast-iron caps C are fitted upon these, as shown in Figs. 32 and 33, to form the connections to the adjoining tubes above and below. The joints for these caps are made each by a single india-rubber washer $\frac{3}{8}$ inch thick, fitted into an annular recess, and secured by a couple of T headed bolts fitting into snugs cast upon the tube heads, with nuts outside.

The two sides of the boiler are enclosed by brickwork, as shown in Fig. 29, which is carried down to form the walls of the furnace chamber B below; and the top is covered in by fire tiles resting on transverse iron girders, with a coating of sand or ashes above to keep in the heat. A row of cleaning holes J J, Fig. 29, closed by stoppers, is formed at each end of the boiler, extending up each side, and serving for examining the boiler and for cleaning the exterior of the tubes from any deposit of soot and dust. This cleaning is done by a small steam jet from a flexible pipe, which is inserted in the

several cleaning holes; and by this means the boiler tubes are readily kept clean, and the passages between them prevented from getting choked. Each end of the boiler is enclosed by a pair of iron doors for the purpose of protection.

The water level of the boiler is at about two thirds of the total height, as shown in Fig. 28. The upper tubes are used as a steam chamber, and communicate with an external steam receiver E, 12 inches diameter, which extends across the top of the boiler. The connections from the several tubes are made by caps fitted upon the top tube-heads in exactly the same manner as the rest of the connecting caps C. There are 90 tubes in all, having a total heating surface of 920 square feet, and 58 cubic feet contents of water including the end caps. A special provision for frequently blowing off the boiler is made by attaching a separate blow-off pipe and cock K at the lower end of each of the bottom tubes, Figs. 28 and 30. These cocks are all opened at regular intervals, depending upon the extent of impurities in the feed water; and each is closed again as soon as the water is seen to run clear from it. The feed water enters the bottom of the boiler at L, at the same end as the blow-off, and is introduced through the double caps that couple the adjoining tubes together. The joints of the feed and blow-off pipes are all made by the same india-rubber washers and bolts as the joints of the tube caps. The several portions of the boiler are all duplicates and completely interchangeable; and there are but three separate patterns in the whole, namely the tubes, with their heads and caps,—besides the steam receiver, and the steam, feed, and blow-off pipes.

A recent modification in the blow-off and feed is shown in Fig. 37, Plate 72, in which the blow-off pipes all discharge into one transverse mud-drum M, and a single blow-off cock at one end of the drum is connected to an internal pipe within the drum, which has an opening opposite each of the branch blow-off pipes. The aperture of the blow-off cock is made larger than the collective area of the holes in the internal pipe, so as to ensure blowing off simultaneously from the whole of the lower row of tubes to the full extent. This arrangement has the advantage of simplicity in requiring attention only to a single cock at the time of blowing off. The feed L is introduced in the

bottom layer of tubes at the opposite end to the blow-off, and the feed pipe is prolonged within each tube by an internal pipe extending about two thirds of the length, with the object of partially heating the feed water before its discharge from the pipe into the boiler.

In this construction of boiler the only portions that are exposed to the action of the fire are the exterior surfaces of the tubes and the inner faces of the cast-iron heads. The tubes are plain cylinders with lap-welded longitudinal seams; and their small diameter, 5 inches and 4 inches, allows of the metal being only $\frac{1}{8}$ inch thick for a steam pressure of 100 lbs. or upwards, with an ample margin of strength, as this thickness gives the same tensile strength as 2 inches thickness in a boiler $6\frac{1}{2}$ feet diameter. The tubes are all proved to a pressure of 500 lbs. per square inch before being fixed in the boilers.

The joints for fixing the ends of the tubes are of very simple and durable character, the tubes being tapped and screwed for 1 inch length into plain cast-iron sockets, as shown in Figs. 32 and 35, Plates 70 and 71; these joints have proved quite durable, never having shown the slightest signs of leakage. The screwed joints are not required to be disturbed for taking out any tubes from the boiler, as the external caps at each end are the only joints requiring to be broken, and the tube with its square head at each end is then free for ready removal by withdrawing it endways. As the joints of the caps are made with the india-rubber washers and are entirely external to the boiler and in cool spaces, the work of breaking and remaking them involves no more difficulty than in ordinary flanged pipes; and this is a point of special importance in the construction of boilers of the class of tube boilers. It has been a point very difficult of attainment to arrange that all the joints which have to be broken in repairing or cleaning the boiler shall be outside the boiler and completely protected from the action of the fire; and to provide the means of removing any portion of the boiler that may be defective, without incurring the necessity and delay of breaking other joints and disturbing other portions of the boiler. Any leakage that may occur is seen at once by simply opening the end doors, since all places where leakage could possibly occur are outside; this

is an important point, inasmuch as ordinary boilers, working in situations where they are not exposed to view or are not accessible for examination without pulling down brickwork, are attended with danger of gradual corrosion from the unobserved leakage of rivetted joints. Injurious action of unequal expansion in boiler plates, which is unavoidable where a portion only of the shell or boiler flue is exposed to the action of the fire whilst the other portion continues comparatively cool, is also avoided in tube boilers of this class, as the tubes are all completely surrounded with the flame or heated gases.

In these boilers with small water-space and small surface exposed to pressure, the object aimed at is not to prevent absolutely the occurrence of explosions, but to diminish the risk of their occurrence; and when any failure does occur, to reduce the amount of destructive power and limit the range of its action, to such an extent that the results shall be rendered practically harmless. Instead of the wide-spread destructive effects arising from the sudden liberation of the large store of explosive force contained in an ordinary boiler, the effects are limited to the rupture of the single tube in which the failure occurs; and the amount of liberated power is not sufficient to cause any injury or displacement in the other portions of the boiler, or any external damage. Several cases of failure of tubes have occurred in boilers of a similar class, but they have rarely caused any external damage or any injury to the boiler attendants.

In addition to freedom from danger, it is required to have such a construction of boiler as will enable repairs in any case of failure to be executed conveniently and quickly, either by replacing the damaged portion, or by shutting off that portion from the rest of the boiler; so that the working of the boiler may be quickly resumed, and the serious expense and inconvenience entailed by the long delay which inevitably occurs in getting to work again after an explosion of an ordinary boiler may be avoided. The writer has not yet had occasion in the two boilers at Ormesby to replace a single tube for repairs; but for the purpose of examination a tube has been withdrawn on several occasions, and replaced by another, the operation being performed in the space of an hour. No difficulty is experienced in breaking the joints for the removal of a tube, or in

making the joints afresh when replacing it by another tube. The rest of the joints are not interfered with at all, but it is found that on starting the boiler again a slight leakage takes place for a short time at some of the joints. Most of these leakages generally take up of themselves; but when they do not do so, a slight tightening of the caps makes all steam-tight. The india-rubber washers of the joints are found to stand thoroughly well, all the original washers continuing in good order, excepting a few originally defective ones that have been replaced. In most boilers of the class having small water-space a serious difficulty has been experienced in the wear and tear and renewal of the screwed joints connecting the tubes; but this has been well met in the mechanical details of the boiler now described. There are two kinds of screwed joints employed in the boiler: the larger and more difficult joints which connect the tube-heads with the tubes, and which are not touched in the process of erecting the boiler, and never require to be disconnected after the joint is made originally in the shop; whilst the other class of joints, which have to be broken and remade in any examination or repairs, are secured merely with ordinary T headed bolts, easily fixed or replaced when worn out.

This boiler is very compact, and occupies small space in proportion to its power; and in respect of portability it possesses great advantages. No piece of the boiler proper exceeds the weight of $1\frac{1}{2}$ cwt., and the heaviest piece in the cast-iron framework which supports the boiler and encloses the fire space is within 11 cwts., and can if required be made compound and the parts limited to 4 cwts. each; a couple of men can handle and place any portion of the boiler proper. There is also an advantage in the facility of setting the boiler, as the brickwork required for setting it consists simply of the foundation walls for the two end bed-plates on which the whole weight is carried; the side walls of the furnace are built entirely outside the boiler proper, and these form the containing walls of the firegrate.

Two of these boilers are employed at the Ormesby Iron Works for supplying steam to the blowing engines for the blast furnaces; and a principal reason which led the writer to decide upon adopting

this construction of boiler was to have the command of a higher pressure of blast. The required increase of power could be obtained within the limit of strength of the engines by an increase in the pressure of steam from 55 to 70 lbs.; but the ordinary cylindrical boilers in use, of 40 feet by 4 feet, would not admit of this extra pressure with safety. On account of the comparatively great strength and safety of these tube boilers, they might as readily be worked at 200 lbs. pressure as at 70 lbs., every tube having been proved in the manufacture to 500 lbs. pressure per square inch.

The boilers are in this case arranged for being heated by the waste gas from the blast furnaces at the Ormesby Works, and the gas is admitted through the two pipes N N at the front of the firegrate, Figs. 28 and 29, Plate 68, one on each side of the grate; the supply of gas is regulated by a valve P in each pipe. The air requisite for the combustion of the gas is admitted through three tubes S inserted within each gas entrance; and the admission is regulated by an end cover-plate having corresponding holes in it, which can be turned so as to cover or uncover the ends of the air tubes partially or entirely. A small fire of coal is kept burning upon the grate, as a precaution against the possibility of any accidental accumulation of unignited gas in the fireplace, which might afterwards occasion an explosion. In experiments made for the purpose of ascertaining the evaporative duty, one of these boilers was temporarily fired with coal instead of with gas; the usual arrangement for firing with coal is shown in Fig. 37, Plate 72.

In respect of evaporative duty, a higher result is not to be expected with this class of boiler than with good ordinary boilers; but the general principle of tubes crossing the course of the flame and heated gases, or placed zigzag so as to expose the heating surface in a position to intercept and break up the heated currents, is distinctly favourable to the absorption of the heat. Where the passages are not so confined as to be liable to become choked or to impede the draught, and where a sufficient space is also allowed in the furnace chamber for the due ignition of the gases, the most important requirements for good evaporative duty are fulfilled.

In making experiments upon the evaporative power of this construction of boiler, many contradictory results have tended to throw doubt upon its real merits; but from actual trials the writer has reason to infer that this has arisen from working the boilers under conditions for which they are not adapted. Thus in working one of the two boilers at the Ormesby Iron Works at simply atmospheric pressure, the evaporative duty obtained per lb. of coal was only about 3 lbs. of water evaporated from 100° temperature of feed water, whilst it was found impossible to evaporate more than 80 gallons per hour from the one boiler; but with the same boiler working at a pressure of 55 lbs. an evaporative duty of 10·27 lbs. was obtained, with an evaporation of 178 gallons per hour. It has to be borne in mind that the steam generated along the sides of the sloping tubes rises to the upper surface, and accumulates as it flows towards the higher end of the tubes, where is the orifice of discharge; and at a low pressure these accumulations of steam will be proportionately large, as compared with the small bulk that the same weight of steam would occupy at a high pressure. The immediate effect therefore is that a larger quantity of water is displaced by the steam in the case of low pressure, whereby the heating surface is materially reduced for evaporative purposes and the generative power of the boiler is materially lowered. The actual presence of this larger bulk of steam is rendered manifest at the gauge glass, where the rise of the water level is very marked when the boiler is worked at a low pressure.

In consequence of the confined spaces in which the steam is generated and through which it has to pass before escaping from the water, there is necessarily a greater tendency for particles of water to be carried away with the steam than in boilers having larger spaces; but this wetter character of the steam is compensated for by the drying effect of the upper steam portion of the boiler, which consists of tubes exposed to the heating gases, and acting therefore as a superheating apparatus. The result is that the steam obtained in the separate steam receiver above the boiler is found to be quite as dry as that from good boilers having large water spaces; and no objection is experienced from priming, except when the boiler is

worked at a lower pressure than that for which it is suited, when exceptional priming arises from the cause that has already been referred to.

In using the general class of boilers having small water-space, disappointments have been experienced from their not continuing at work without serious difficulties in keeping them in order; but it cannot be expected that the more complicated and delicate structure of these boilers can admit of the same rough handling and marked absence of systematic attention that so commonly occur with the ordinary cylindrical boilers; and it must be recognised as an unavoidable consequence that a better class of boiler attendants is required for working such boilers satisfactorily than is customary with ordinary boilers. But in the writer's opinion this should not be considered as any real objection to the boiler; it is rather a reason in its favour, as compelling attention to the acknowledged importance of improving the class of ordinary boiler attendants. It is not meant however to imply that constant attention from a skilled mechanic is either necessary or desirable for keeping the boiler in working order; but simply such a better class of systematic attention as shall ensure that the very simple but necessary conditions of success are steadily carried out. For instance, in the matter of blowing-off, which only corresponds to the ordinary regular blowing-off of marine boilers, it has been found with the dirty water used at the Ormesby Iron Works that the blowing-off must be performed regularly every four hours, an interval of six hours having in that case proved too great to prevent the formation of incrustation within the boiler. Again at the end of a certain period, dependent on the quality of the water used, the boiler must be laid off for cleaning internally, otherwise the tubes and caps would be liable to become choked up; and in the Ormesby boilers six weeks has been the extreme limit beyond which the boilers could not be worked. In these boilers the arrangements for effecting the cleaning are so simple that the boiler has only to be stopped from 18 to 24 hours for the purpose. Regularity of firing and steadiness of feed are also matters requiring stricter attention than in boilers which themselves contain several hours' supply of water. In reference to all the above points, it is a significant fact

that in the United States, where there is a greater necessity than in this country for light boilers working at high pressures, this class of small water-space boiler is in extensive use with satisfactory results.

The President remarked that it was evidently desirable for more attention to be given to the use of a higher pressure of steam than was generally employed in boilers at present; and an increase of pressure would necessitate the adoption of boilers having small steam and water spaces exposed to the pressure, in order that safety in working might be ensured. The Root boiler now described appeared to him a very satisfactory construction of boiler for meeting these requirements, and greatly superior to the cast-iron boiler that had been referred to, which had lately undergone a fair trial in this country, but had not proved successful. It would be interesting to know the results of the new boiler after it had been a longer time at work; and he enquired whether it was possible from the present experience of its working to point out the direction in which any difficulties might be expected to be met with.

Mr. C. Cochrane mentioned that he was indebted to Mr. Marten for kindly supplying the materials and drawings for the first portion of the paper, in which the gradual development of the class of boilers constructed with small water space and small surface exposed to pressure was traced from the earliest attempts up to the introduction of the Root boiler into this country. He had found this boiler so thoroughly satisfactory in working that he thought it would be difficult at present to indicate any weak points; the only attempt at improvement had been in connection with the mode of introducing the feed water, by feeding through a separate branch into each tube in the bottom row; but his experience led him to prefer the original simpler plan, in which the feed was introduced through the caps coupling two tubes together, as

shown in Fig. 30; the separate branches in some cases required springing into their places, and the flanges were liable to fracture. The modification in the mode of blowing off, shown in Fig. 37, was one that he had not yet tried, and it did not appear to him of material importance; it was intended for avoiding a multiplicity of blow-off cocks, and might answer well; but in the meantime he was quite satisfied with the present plan of having a separate blow-off cock to each of the bottom tubes, which was found to answer thoroughly.

Mr. W. Cochrane observed that the record of failures was as important as that of successes, and having himself made a thorough trial of two of the Harrison cast-iron boilers at the Elswick Colliery, Newcastle, he had found after twelve months' trial that they were a complete failure and had to be abandoned. The theory that the alternate expansion and contraction of the balls would break the scale off their interior surface, and that it could then be blown off in emptying the boiler, was not borne out by practical experience; on the contrary the balls became encrusted with scale, and then began to crack, one after another. The expense of unfixing the sections of the boiler and replacing the cracked balls had been very serious indeed; and this had to be done whenever a crack occurred, which happened several times during the twelve months that he had continued the trial of the boiler.

Mr. E. B. Marten said he had tried experiments with the Root boilers at the Ormesby Iron Works, and was satisfied they would do the amount of duty stated in the paper. In making experiments however with many others of the high-pressure boilers that had been referred to, he had not succeeded in getting such a high duty as they were said to be capable of yielding; but this was because in those cases the boilers at the time of the experiments had not been working at so high a pressure as they were intended to bear. The Perkins and Benson boilers, shown in Figs. 11 and 19, had been worked at a very high pressure, and where the engines were capable of taking advantage of the high pressure these boilers had been successful; but his own experience was that such boilers were not useful at the ordinary lower pressures of only 30 to 40 lbs. per square

inch. He had very lately seen the working of the Benson boiler at Wednesbury, where it had now been at work regularly for the last eleven years at from 60 to 70 lbs. pressure, and had proved entirely successful; and it was found impossible to overheat it when the feed water was clean, as it absorbed the whole of the heat when the firing was forced to the utmost extent, and it did not prime even under the heaviest firing.

Mr. J. WHITLEY thought that in the use of boilers having small water spaces one point of importance was that they should be supplied as far as possible with pure water, in order to avoid any formation of deposit in the boilers. For this purpose a plan of purifying the feed water from earthy matters had lately been introduced from America, by which the mineral matter was deposited as a soft mud before the water entered the boiler, and the boiler was thus relieved from all incrustation; the feed water was also raised to the boiling point in this process.

Mr. H. KESTERTON mentioned that a marine boiler of 400 nominal horse power on the Root plan had been made at the works with which he was connected in Birmingham, and had been applied to the screw steamer "Malta," running between London, the Mediterranean, and the Baltic, and was in that case fed entirely with condensed water from a surface condenser, with the exception of about 11 per cent. of salt water required to make up the waste. After the ship had run about 32,000 miles, the boiler tubes were found to be perfectly clean internally, while the consumption of coal had been 8 tons per day less than with the ordinary marine tubular boilers previously used, when doing the same work. A slight accumulation of slimy deposit which had been found in the mud drum was due to the circumstance of the blow-off cock having been put in the centre of the end cover of the mud drum, instead of at the bottom; consequently the blow-off took effect only on the upper half of the mud drum, and an accumulation of slime took place in the lower half.

Mr. L. OLRICK considered that many of the difficulties experienced with steam boilers arose from overworking them, in consequence of their having been made originally too small, with a view to economy in first cost; and the simple remedy in such cases was to get the

boilers large enough in the first instance. Another point that was frequently overlooked was the necessity of ensuring an efficient circulation of the water in a boiler; where there was perfect circulation the maximum effect would be obtained from the fuel, but not otherwise. In tubular boilers the efficiency of the circulation that could be obtained would depend largely upon whether the tubes were properly arranged. In the case of vertical tubes open at both ends, such as the Galloway tubes, the circulation was very fair; the cooler water entering at the bottom of the tube from the water space beneath became heated and partially evaporated in the tube, and formed an ascending current of mixed steam and water, which flowed upwards and out at the top of the tube into the water above, thereby creating a good and entirely natural or self-acting circulation. In using tubes closed up at the bottom end and suspended in the furnace, it was necessary to add an internal tube for separating the descending and ascending currents from each other, without which it was found that no circulation could take place; but with this provision perfect circulation was obtained. The Field boiler, constructed in this manner, although peculiarly advantageous for purposes where rapidity of raising steam was of special importance, as in the case of steam fire-engines, was by no means limited to such applications; upwards of five hundred of these boilers were already at work in connection with ordinary stationary engines. The usual dimensions of a boiler of 50 horse power, having 500 square feet of heating surface in the tubes and 130 square feet of heating surface in the firebox, were 13 feet height and $6\frac{1}{2}$ feet diameter, showing that this description of boiler took up but very little space in proportion to the extent of heating surface.

With horizontal or inclined tubes, arranged as in the Belleville or Root boilers, he did not see how a perfect circulation could exist; the cause of the circulation in any boiler was the evaporation of the steam, and the consequent rising current of steam bubbles from the heating surfaces was attended with a corresponding downward current of water to supply its place. This could take place freely in vertical tubes, but in horizontal tubes where the water was inside the tubes there could be no such tendency to

the formation of currents; and he could not understand therefore how there could be any true circulation in horizontal or inclined tubes, according to the true meaning of circulation, which he understood to be an uninterrupted natural flow of water contiguous to the heating surface, so as to counteract the tendency of the steam to cling to the heating surface; the only movement which he thought could take place in such a case would be what might be called commotion of the water, as distinguished from circulation. In the Benson boiler it was true that an efficient circulation was obtained with horizontal tubes; but this was done artificially, by means of a circulating pump forcing the current of water through the tubes, and he agreed in considering it a disadvantage for the working of the boiler to be dependent upon a pump, because if the pump ever failed the boiler would become stopped; and he thought any self-acting circulation, however slight, was better than a forced circulation depending upon artificial means. Another point to be considered in that boiler was the friction to be overcome in forcing a stream of water through so great a length of tubes of small diameter and with many bends; and it appeared to him that the amount of power required to be expended in working the circulating pump would be quite disproportioned to any economy that could be obtained from such a construction of boiler; this he believed to be the reason why that boiler had not come into general use. The Belleville boiler was another with horizontal tubes, in which there was no provision for ensuring circulation of the water; and he considered the only way to obtain circulation in that construction of boiler would be to raise the water level as high as the steam reservoir on the top of the boiler, and provide a series of back return tubes from that point to the bottom tubes of the boiler, so that the water after separation from the steam in the steam chamber might return at once to the bottom tubes of the boiler, without interfering with the currents of mixed steam and water rising through the upper tubes. The Belleville boiler he believed was at present largely used in the French navy, notwithstanding that it had the further disadvantage that all the joints of the tubes were exposed to the fire. In the Allen boiler, with inclined stopped tubes suspended over the fire, there was no

means of separating the upward and downward currents in each tube; and without such provision he did not consider it would be possible to obtain an efficient circulation.

In the Root boiler at the Ormesby Works it had been stated in the paper that the extent of heating surface was 920 square feet; and he enquired what was the horse power of that boiler, taking one horse power to be equivalent to an evaporation of one cubic foot of water per hour. The evaporation had been given as $10\frac{1}{4}$ lbs. of water per lb. of coal in that case; but in another of these boilers of 30 horse power, working in Birmingham, he understood the consumption of coal had been 25 cwts. in a trial of ten hours' duration, and at the above rate per horse power this result would correspond to an evaporation of only 6·7 lbs. of water per lb. of coal; he should be glad to know therefore whether the higher evaporative duty had been substantiated by continued experience with the boilers at Ormesby. A great improvement he observed had been made in the cast-iron caps at the ends of the tubes, by increasing the area of passage through them, which had previously been much too small to allow the steam to pass upwards with the requisite facility. In the modified arrangement for the feed and blow-off that was shown in Fig. 37 he noticed the addition of an internal tube for introducing the feed in the bottom row of tubes, which did not appear to have been used in the boilers at Ormesby; and he enquired whether it was intended to adopt that plan of introducing the feed, or whether the present mode of feeding was found satisfactory. He fully concurred in considering that boilers of this description ought not to be exposed to the same rough usage or worked by the same class of attendants as the common egg-ended boilers, and that attention of a superior character was requisite to ensure their proper working.

Mr. C. Cochrane said that, in reference to the suggestion which had been made for freeing the feed water from impurities before it was supplied into the boiler, he fully appreciated the importance of using pure feed water, and intended shortly to get the whole of the water distilled for the boilers at his works, in order to avoid the necessity for blowing off every four hours and laying off the boilers every six weeks for cleansing as was now done, the present supply

of water being exceptionally bad in quality. The deposit that was formed in the boiler tubes was found to be greatest in the bottom row but one, and gradually diminished in the rows above; in the sixth row from the bottom and in all the rows above there was scarcely any deposit perceptible, and the bottom row itself was also found to continue quite free from deposit, and had never required to be cleaned out. In the tubes where deposit did occur, it readily scaled off the sides of the tubes in pieces 2 or 3 inches square, and the greater part worked its way down into the mud drum at the time of blowing off, and was thus got rid of at once; what remained in the tubes was easily raked out when the end caps were removed, by inserting a rod with a semicircular end.

As regarded the circulation of the water in the Root boiler, he had come to the conclusion that there was very little difference between the circulation in this boiler and that in an ordinary plain cylindrical boiler, and probably in each case there was not really anything that could be called definite circulation. The feed water was introduced at the lowest end of the bottom row of tubes, and the steam generated in the tubes made its way to their upper ends, in consequence of their inclined position, and then flowed upwards in a tortuous course through the end caps into the steam chamber at the top of the boiler. A gradual forward movement of the water from the feed entrance towards the upper part of the boiler was thus produced, which he believed was all the motion that actually took place within the boiler. The prolongation of the feed pipe within the bottom row of tubes was a suggested modification which he had not tried himself and did not think it necessary to adopt, as he did not see at present that it would be an improvement in the boiler; and whenever he had occasion to erect any more boilers of the same kind, the present ones would be followed in every detail, having proved so thoroughly satisfactory for the purpose desired. Each of the two boilers now at work was considered to be of 65 horse power, but he believed they had not yet been worked higher than 32 horse power, owing to the feed being at present intermittent and the supply limited to only half the quantity of water requisite for working them up to their full power.

Mr. H. Kesterton remarked that, in regard to the difference in the duty obtained from the Root boiler at Ormesby and from the boiler at Birmingham which had been referred to, the latter was made from the original designs and was one of the first of these boilers started in England, and it was found that the cast-iron caps connecting the ends of the tubes were too small to allow the free escape of steam from the tubes and the access of water to them; the practical result was that in that boiler the fuel was to a great extent employed in heating steam which could not escape, but in the case of the Ormesby boiler these connections were about 40 per cent. larger, so that the steam could escape much more readily, and a consequent economy of fuel had been the result. In the Ormesby boiler also the tubes were arranged differently from those in the Birmingham boiler, being placed about half as much further apart in all directions, the result of which was to cause a more free passage for the flame and heat among the tubes.

Mr. E. Gilkes enquired whether any trial had yet been made of firing the boiler with the waste gas from the blast furnaces, and whether it was suitable for being worked in that way.

Mr. C. Cochrane replied that the two Root boilers at the Ormesby Works had been specially arranged for using the blast-furnace gas, and worked in that way with complete success; one of them had been fired for some time experimentally with coal, also with complete success. The only difference between a boiler purposely constructed for gas and one to be fired with coal was that with the gas he had found it important to increase the length of traverse for the flame amongst the boiler tubes, in order that the heat might be more thoroughly absorbed before reaching the chimney flue; a third deflecting plate had therefore been added in these boilers fired by gas, as shown in Figs. 28 and 30, while the ordinary make of the boilers for firing with coal had only two deflecting plates, as shown in Fig. 37.

Mr. W. Thompson enquired what was the consumption of coal per hour with this boiler relatively to the water evaporated.

Mr. T. Whitwell asked what was the temperature of the waste heat escaping to the chimney. In a boiler which he had seen

working at Charleroi in Belgium the temperature of the waste heat had not exceeded 350° Fahr.

Mr. G. D. HUGHES enquired whether any difficulty had been experienced from the deflecting plates becoming warped or bent in the boilers that were fired with coal instead of blast-furnace gas; and whether any of the plates had given way, or had required to be replaced. In the instance of a boiler of this construction which he had lately seen at Nottingham, it had been found that the deflecting plates would not stand the heat from the fire, and were warped by it; and in consequence of the feed water containing carbonate of lime, the tubes became rapidly encrusted with scale, and those in the bottom row were continually being burnt out and requiring renewal; the result was that in a few weeks the boiler had had to be abandoned as useless.

Mr. C. COCHRANE replied that the consumption of coal in one experiment which he had made with the boiler at the Ormesby Works had amounted to 633 lbs. during a period of 3 hrs. 33 mins., and the quantity of water evaporated during the same time had been 630 gallons; the results were therefore a consumption of 178 lbs. of coal per hour, and an evaporative duty of nearly 10 lbs. of water per lb. of coal. The temperature in the chimney flue during this time ranged from 300° to 366° Fahr., the firing being with coal. The deflecting plates had not given any trouble, nor was there the slightest appearance of their requiring renewal, as they were not even warped. As however the heat in firing with coal was so much greater than with gas, there was of course greater risk of the plates being injured; and on that account he thought the preference was certainly to be given to gas, which was as safe as possible, and had caused no trouble whatever in the boiler in which it was used.

Mr. H. KESTERTON said that where the deflecting plates had been put in in the same shape and position as those shown in the drawing they had given no trouble and had not required to be replaced. The boiler at Nottingham which had been referred to as having been abandoned was one of the first made, and he had no doubt the failure was owing solely to the cause named before, of the steam passage through the end caps being too small, aggravated in that

case by the fact of the boiler being much too small for the amount of work required of it; it was put up to work a flour mill, and was very heavily fired and badly used, being worked night and day without any stopping for cleaning out the boiler, and the regular blowing off that was requisite for keeping it clean had been neglected.

Mr. W. Clay observed that for marine purposes the increasing importance of having light boilers which would work safely at higher pressures of from 60 to 120 lbs. per square inch was now very generally recognised, and it was evident that such boilers must be very different in construction from the ordinary marine boilers at present in use. Although the latter were no doubt properly constructed in the first instance, and originally of ample strength, yet when it was considered that in the course of a few years they inevitably became seriously weakened by leakages which escaped detection, there was great reason for anxiety in continuing their use. If therefore such boilers as the Root or Field could be brought into practical use as marine boilers, without being attended with the defects which hitherto had generally accompanied boilers made in so many separate pieces, he considered it would be a great step in advance, and would largely increase the safety of ocean navigation.

Mr. H. Kesterton mentioned that a marine boiler on this construction was now being made to work at a pressure of 160 lbs. per square inch.

The President said he concurred in considering that the subject of increased safety in steam boilers was one of very great importance, more particularly with a view to the use of higher pressures in marine boilers, in which there was not only greater liability to explosion than in other classes of boilers, but the occurrence of an explosion was inevitably attended with very serious results. The only way of meeting the difficulty was by the use of strong light boilers having a multiplicity of separate small water spaces, any one of which might fail without producing any serious damage and without affecting the safety of the rest of the boiler. A locomotive boiler did not fulfil these conditions, because the external shell was itself a large vessel, containing the whole body of water without subdivision. In the paper now read a valuable and practical review had been

given of the principal attempts which had previously been made to construct high-pressure boilers with small water spaces; but not many of these had proved so satisfactory in practice as to continue in use to the present time, and it was therefore necessary that much caution should be exercised in adopting any new plan, and that particular pains should be taken to ascertain the direction in which any possible failure might be apprehended. From the information which had been given respecting the working of the Root boiler now described, there appeared every reason to hope that it would prove successful in continued working; and the results already obtained with it would be of much value in directing attention to a mode of meeting one of the great wants of the present time, namely the production of high-pressure steam with safety and economy. One point of detail that he wished to enquire about in the working of the boiler was what facilities there were for sweeping the flues; the experience with locomotive boilers showed the importance of keeping the tubes well cleaned out, and in the present boiler it was the outside of the tubes that would have to be cleaned.

Mr. C. Cochrane replied that the cleaning of the outside of the tubes was readily accomplished by means of the series of side apertures (J J, Fig. 29,) at the front and back of the boiler; these openings were each 4 inches wide by 8 inches high, and were closed by stopper doors in ordinary working. By introducing a steam jet from a flexible pipe at any of the cleaning holes the soot and dust were effectually blown off the surfaces of the tubes; and the deflecting plates were scraped clean by inserting rods through the same holes. There was no difficulty in reaching any part of the boiler in this way, and the operation of cleaning was thus a very simple one, and could be performed while the boilers continued under fire, as had been done at the Ormesby Works without any difficulty.

Mr. T. Bell enquired whether the necessity of laying off the boiler every six weeks for cleaning internally, as mentioned in the paper, applied to the boiler fired with coal or by gas, or to both of them; and also whether the evaporative duty was as good in the last week of the six as in the first, and whether the experiment which had been made on the evaporative duty gave the result when

the boiler had been newly cleaned, or when it had gone some time without cleaning.

Mr. C. Cochrane replied that each of the two boilers at the Ormesby Works required to be laid off every six weeks for cleaning internally, one of them being fired with coal and the other with gas. At the time of making the experiment upon the evaporative duty of the boiler fired with coal, it was under the most favourable conditions, having just been cleaned both externally and internally; the duty would of course not be quite so good at the end of the six weeks' working, but he had not ascertained what difference there was in this respect.

Mr. W. Ford Smith observed that it appeared the boilers at the Ormesby Works were at present worked only to half their nominal power, and he enquired whether they would not have to be cleaned more frequently when worked to their full power, as the incrustation would then be much more rapid; otherwise he thought the same result might be apprehended as in the overworked boiler at Nottingham, the incrustation becoming so serious as to choke the tubes and render the boiler useless. It appeared to him a very important matter that the proper proportion of the grate surface to the heating surface should be ascertained in these boilers, because it was clear that if the grate surface were too large it must tend to the more rapid destruction of the boiler.

Mr. C. Cochrane replied that in firing the boilers to their full power the incrustation would of course be double what it was now that they were worked only to half their power; and with the present bad quality of water it would then be necessary to clean them out every three weeks, instead of every six as at present. To avoid the necessity of stopping the boilers so frequently for removing the incrustation, the importance of using pure water was obvious; unfortunately the boilers at the Ormesby Works were most unfavourably circumstanced in this respect, the water supplied to them being very foul indeed, and they were thus working under the worst possible conditions for freedom from incrustation.

Mr. F. C. Marshall enquired whether it was salt water that was used in the boilers. The question of boilers adapted to high pressures and suitable for marine purposes was now becoming a very important one. Boilers of the construction described in the paper would meet the first requirement, and any experience in connection with their working was very valuable.

Mr. C. Cochrane replied that it was not salt water that was used, but waterworks water which had previously been employed for various other purposes in the ironworks, and was very dirty by the time it was supplied to the boilers.

The President moved a vote of thanks to Mr. Cochrane for his paper, which was passed.

The President moved a vote of thanks, which was passed, to the Cleveland Institution of Engineers for the very cordial and handsome reception given to the Institution on the occasion of the present Meeting at Middlesbrough; to the Local Committee and the Honorary Local Secretaries, Mr. Jeremiah Head and Mr. Gilbert Gilkes, for the excellent arrangements and their active exertions in promoting the success of the Meeting; to the Proprietors of the various Works and Mines so liberally thrown open to the visit of the Members; and to the North Eastern Railway Company for the important facilities so liberally afforded to the Members for visiting the Works and for the Excursions.

The Meeting then terminated.

In the afternoons of Tuesday and Wednesday the following Blast-Furnace Works, Rolling Mills, and Engineering Works in Middlesbrough were opened to the visit of the Members. A collection of Engineering Models and Specimens was also exhibited in the Exchange, which with the Cleveland Club was opened to the Members during the week of the Meeting, by the kindness of the Directors of the Exchange and the Committee of the Club.

Messrs. B. Samuelson and Co., Newport Blast Furnaces.

Messrs. Fox Head and Co., Newport Rolling Mills.

The West Marsh Iron Co. Rolling mills.

The Britannia Iron Co. Rolling mills.

Messrs. Gjers Mills and Co., Ayresome Blast Furnaces.

Messrs. Hill and Ward, Newport Wire Mill.

Messrs. Jones Brothers and Co., Ayrton Sheet Mill.

Messrs. William Bacon and Co., Acklam Refinery.

Messrs. Stevenson Jaques and Co., Acklam Blast Furnaces.

Messrs. Lloyd and Co., Linthorpe Blast Furnaces.

Messrs. Hopkins Gilkes and Co., Tees Side Iron Works. Blast furnaces and rolling mills.

Messrs. Hopkins Gilkes and Co., Tees Engine Works. Foundry and bridge building.

Messrs. Bolckow Vaughan and Co., Middlesbrough Iron Works. Rolling mills, foundry, and salt mine.

The Cleveland Bolt and Nut Works.

Messrs. Bell Brothers, Clarence Iron Works. Blast furnaces.

Messrs. Backhouse and Dixon, Cleveland Iron Ship Yard.

The Middlesbrough Dock Extension Works.

Messrs. Gilkes Wilson Pease and Co., Tees Blast Furnaces, and chair foundry.

Messrs. Hjerlied and Spence, Marsh Road Engine Works.

Messrs. Cochrane Grove and Co., Ormesby Foundry, pipe foundry, engine and boiler works.

Messrs. Cochrane and Co., Ormesby Blast Furnaces.

Messrs. Jones Dunning and Co., Normanby Blast Furnaces.

Messrs. Swan Coates and Co., Cargo Fleet Blast Furnaces.

On Thursday, 27th July, an Excursion was made by the Members to visit the following Iron and Engineering Works at Stockton :—

Messrs. William Whitwell and Co., Thornaby Iron Works. Blast furnaces and rolling mills.

Messrs. Head Wrightson and Co., Teesdale Iron Works. Foundry and bridge building.

The North Yorkshire Iron Co. Rolling mills.

Messrs. Richardson and Duck. Iron Shipbuilding Yard.

Messrs. M. Pearse and Co. Iron Shipbuilding Yard.

The Stockton Furnace Co. Blast furnaces.

Messrs. Blair and Co. Marine Engine and Boiler Works.

Messrs. R. Morton and Co., Bishopton Lane Brass Works.

The West Stockton Iron Co. Rolling mills.

Messrs. Houldsworth and Co., Westbourne Iron Works. Rolling mills.

Messrs. Henry Wilson and Co., Phœnix Brass Works.

Messrs. Smith and Thompson. Millfield Iron Foundry.

The Bousefield Iron Co. Rolling mills.

The Norton Iron Works. Blast furnaces and foundry.

The North of England Industrial Iron Works, Carlton. Blast furnaces.

From Stockton the Members proceeded by special train to visit the Clay Lane and South Bank Blast Furnaces of Mr. Thomas Vaughan at Eston, the Cleveland Blast Furnaces of Messrs. Bolckow Vaughan and Co., and the Rolling Mills of Messrs. Jackson Gill and Co.; the Lackenby Iron Works, where the new compound-cylinder blowing engines described in the paper read at the meeting were seen in course of erection, with surface condensers and Howard boilers; and the South Gare Breakwater, constructed of blast-furnace slag, where the tipping of the slag for the formation of the breakwater was witnessed. In the evening the Members were entertained at Dinner at the Zetland Hotel, Saltburn, by the invitation of the Members of the Cleveland Iron and Engineering Trades, in celebration of the Middlesbrough Meeting of the Institution.

On Friday, 28th July, the Members were taken by special train to visit the following Ironstone Mines of the Cleveland District, in the neighbourhood of Guisbrough and Saltburn, the levels and workings being specially lighted up for the occasion:—the Spa Mine, the Cliff Mine, and the Huntcliff Mine, of Messrs. Bell Brothers; the Liverton Mine, and the adjoining Kilton Viaduct; and the Lofthouse Mine of Messrs. J. and J. W. Pease at Skinningrove. The Members were entertained at Luncheon at

Skinningrove, by the invitation of the Members of the Cleveland Iron and Engineering Trades.

On Saturday, 29th July, the following Engineering, Iron, and Shipbuilding Works at Darlington and Hartlepool were opened to the Members:—

Darlington.

The Shildon Locomotive Works.
The South Durham Iron Co. Blast furnaces.
The Darlington Forge Co.'s Works.
The Darlington Wagon Works.
Messrs. Pease Hutchinson and Co., Skerne Iron Works.
The North Eastern Railway Locomotive Works.
Messrs. C. Ianson and Co., Whessoe Foundry.
Messrs. Lister and Co., Hopetown Foundry.
Messrs. Fry Ianson and Co., Rise Carr Iron Works.
Messrs. Henry Pease and Co., Priestgate Woollen Mills.
The Stockton and Middlesbrough Water Works, Pumping Engines and Reservoirs at Coniscliffe.

Hartlepool.

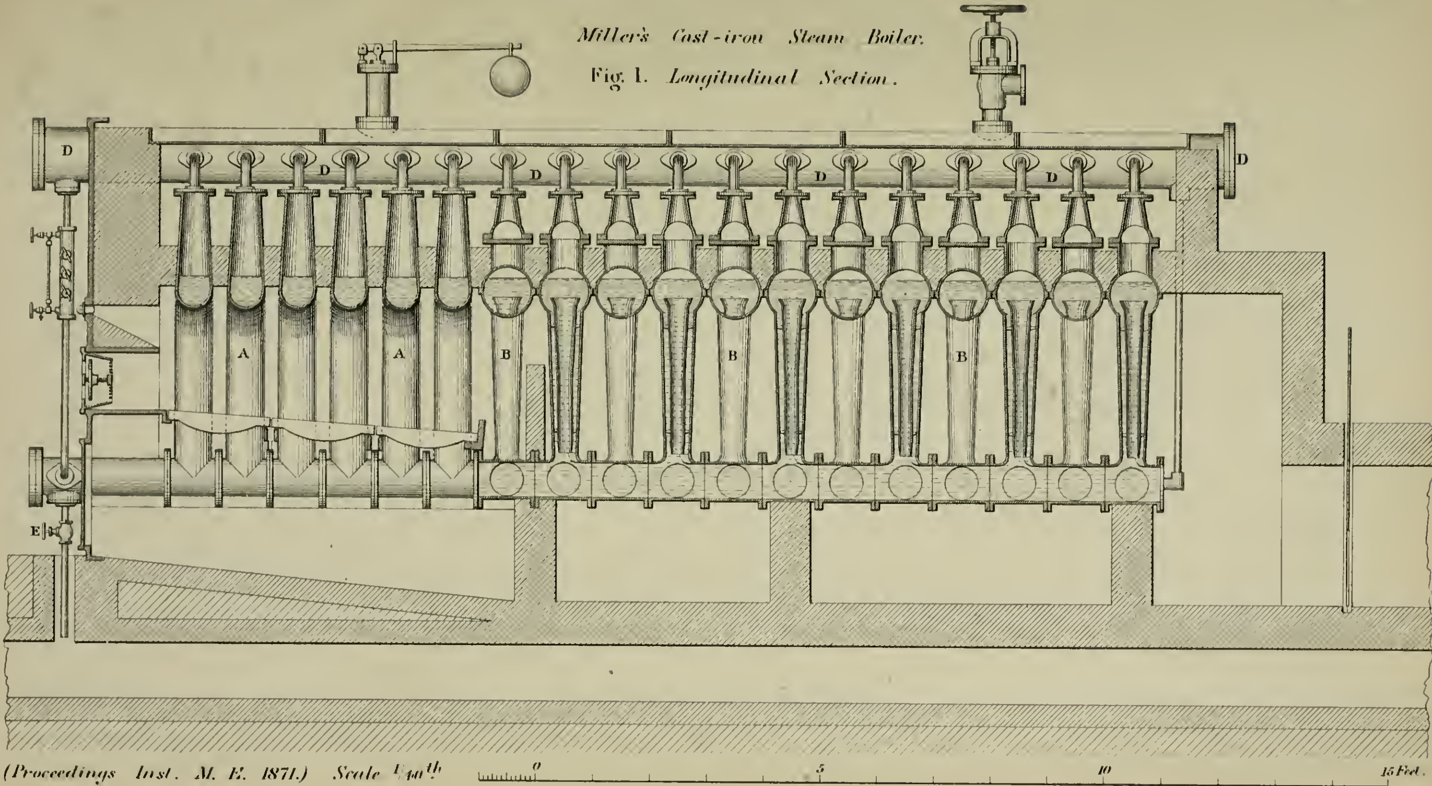
Messrs. Thomas Richardson and Sons. Rolling Mills and Marine Engine Works.
Messrs. Denton Gray and Co. Iron Shipbuilding Yard.
Messrs. Withy Alexander and Co. Iron Shipbuilding Yard.
The Hartlepool Malleable Iron Co.'s Works.
Large Docks, Warehouses, &c.

Also the Middleton Blast Furnaces, of Messrs. George Wythes and Co.; and the Grosmont Iron Works, of Messrs. C. Bagnall and Co.

CAST-IRON STEAM BOILER.

Miller's Cast-iron Steam Boiler.

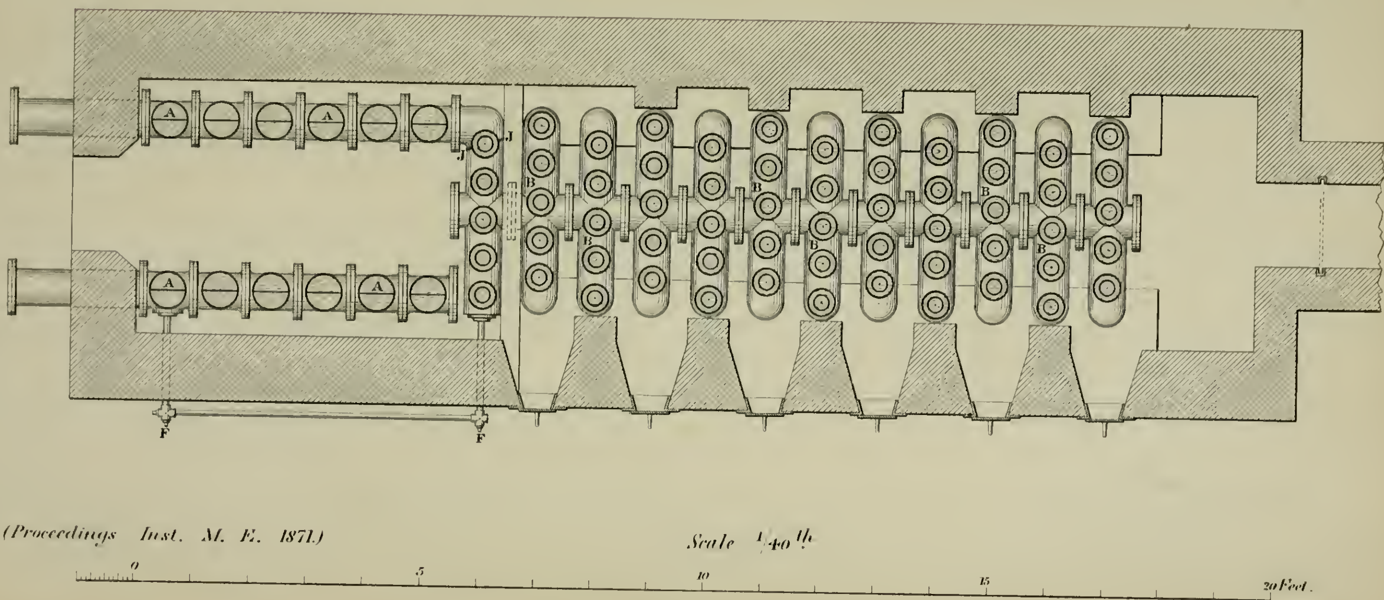
Fig. 1. *Longitudinal Section.*



 Scale 1/40th

CAST-IRON STEAM BOILER.

Fig. 2. *Sectional Plan.*



Scale 1/40th.

(Proceedings Inst. M. E. 1871.)

CAST-IRON STEAM BOILER.

Boiler applied to Balling and Re-heating Furnaces.

Fig. 3. *Longitudinal Section.*

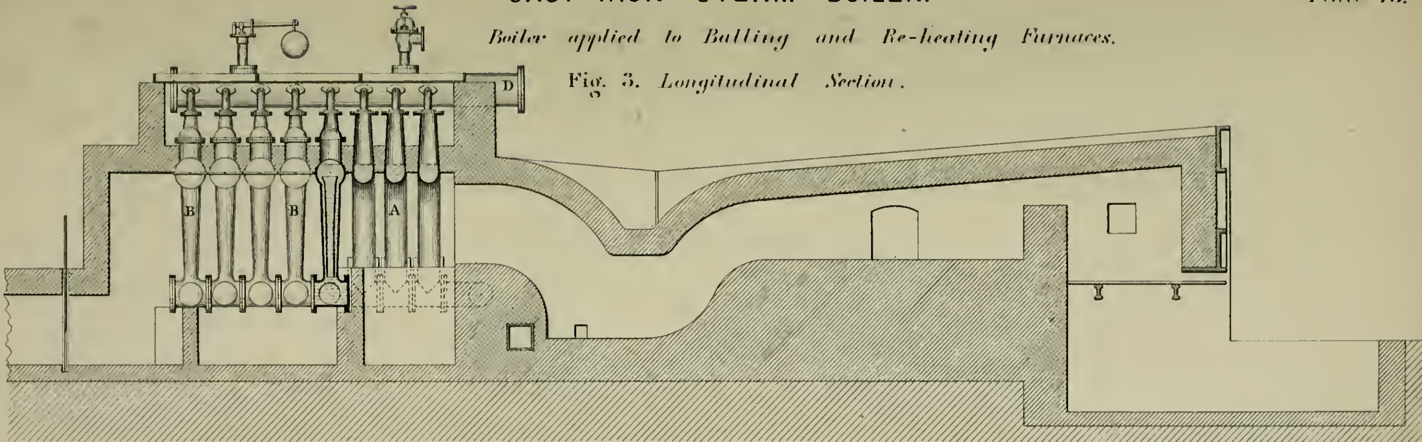
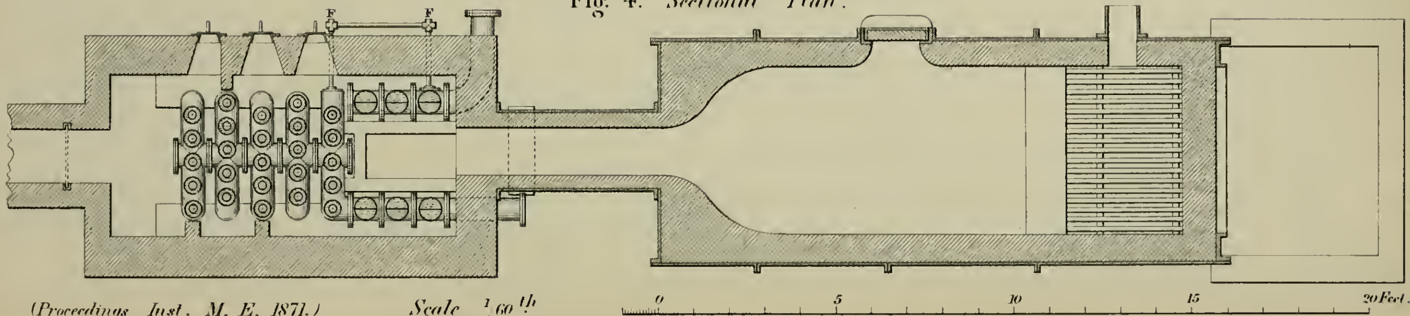


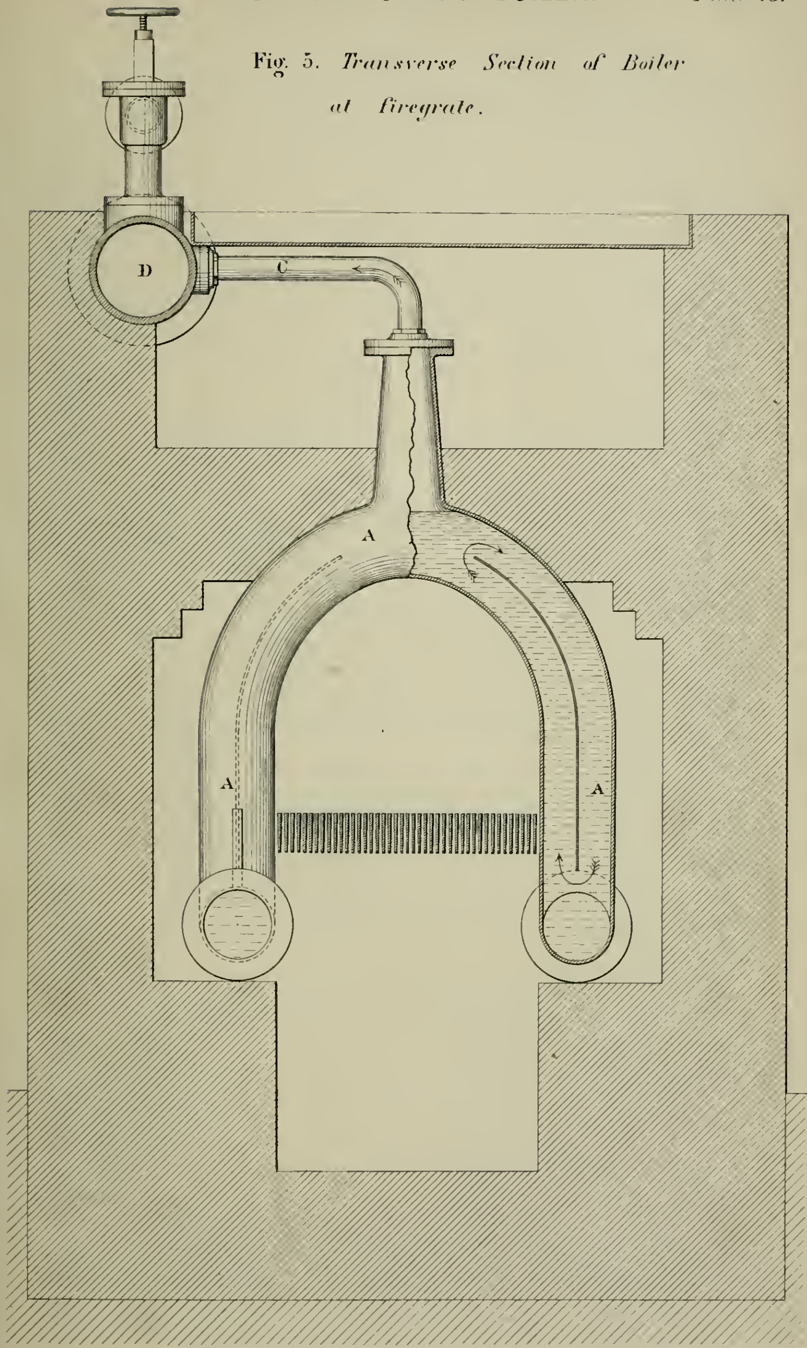
Fig. 4. *Sectional Plan.*



(Proceedings Inst. M. E. 1871.)

Scale 1/60th

Fig. 5. *Transverse Section of Boiler at firegrate.*

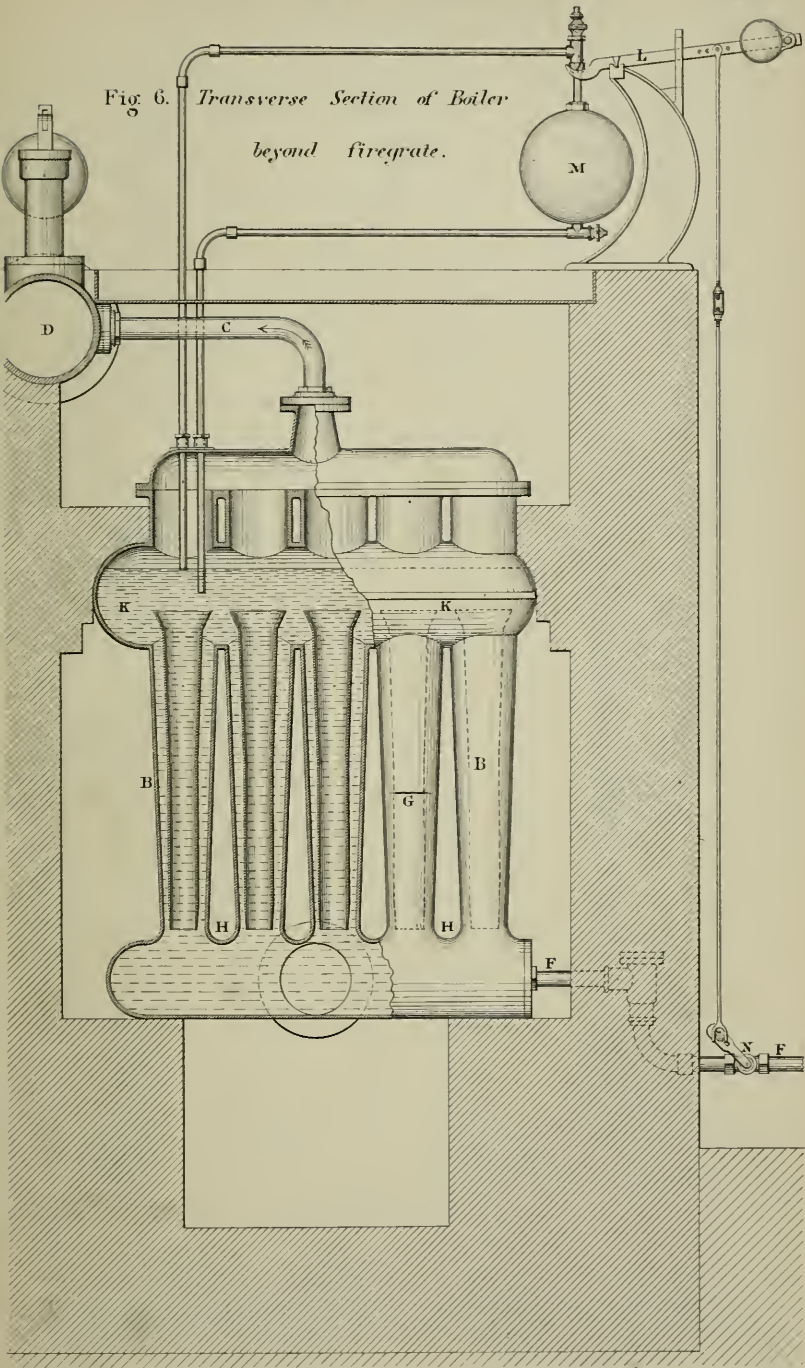


Scale 1/20th

Ins. 12 6 0 1 2 3 4 5 Feet.

CAST-IRON STEAM BOILER. *Plate 77.*

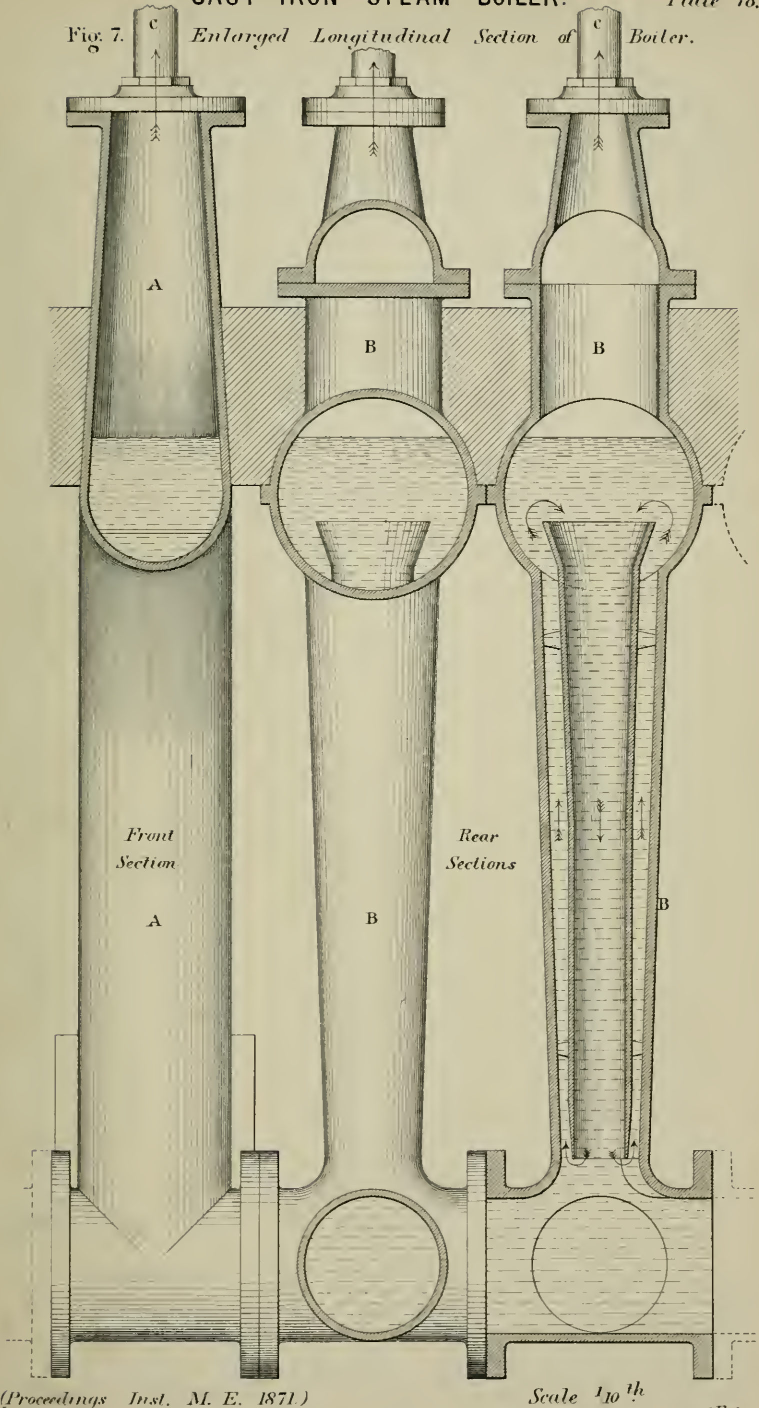
Fig. 6. *Transverse Section of Boiler beyond firegrate.*



(Proceedings Inst. M. E. 1871.) *Scale 1/20th*

Ins. 12 6 0 1 2 3 4 5 Feet.

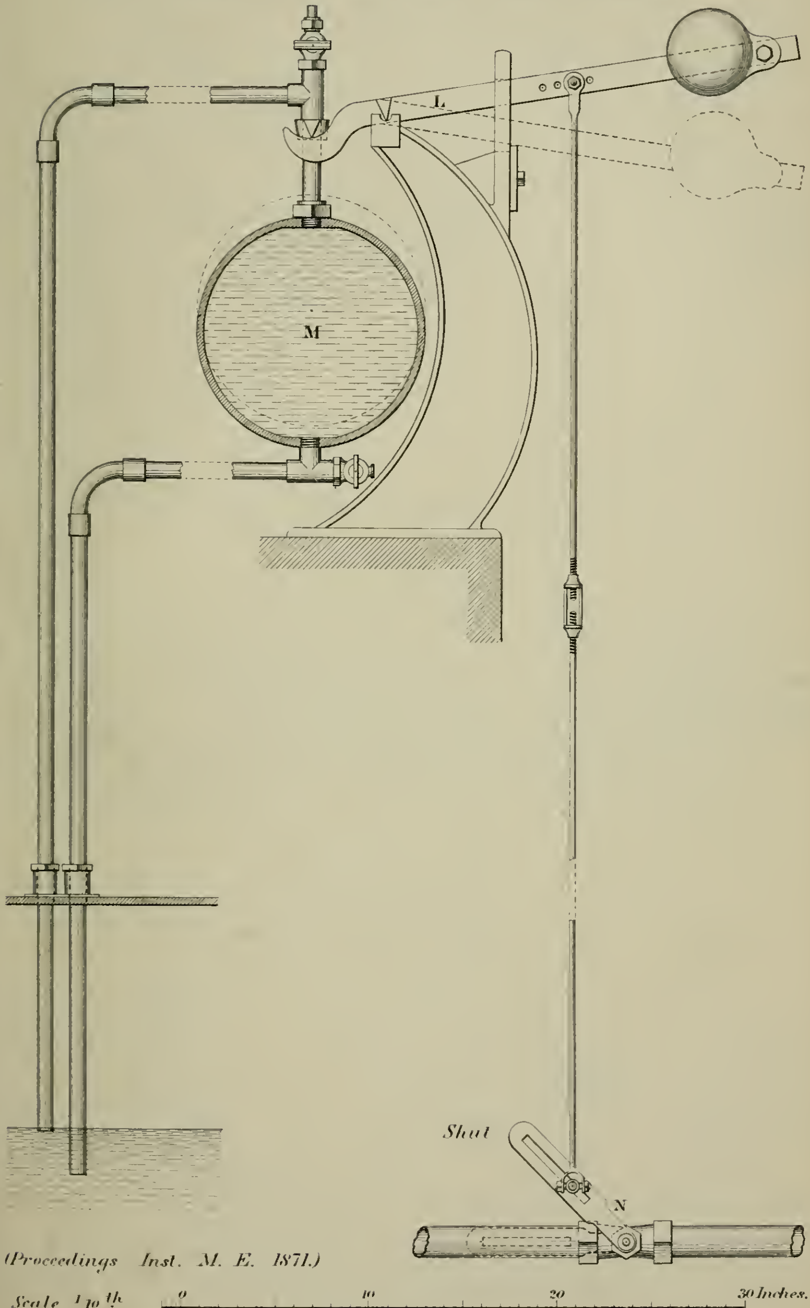
Fig. 7. *Enlarged Longitudinal Section of Boiler.*



(Proceedings Inst. M. E. 1871.)

Scale $1/10^{th}$

Fig. 8. *Berryman's Self-acting Feed Apparatus.*



(Proceedings Inst. M. E. 1871.)

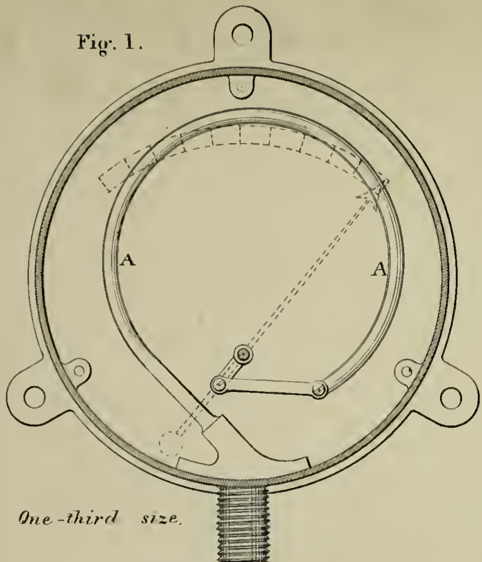
Scale 1/10th

STEAM PRESSURE GAUGES.

Plate 80.

Bourdon Gauge.

Fig. 1.



One-third size.

Fig. 2.

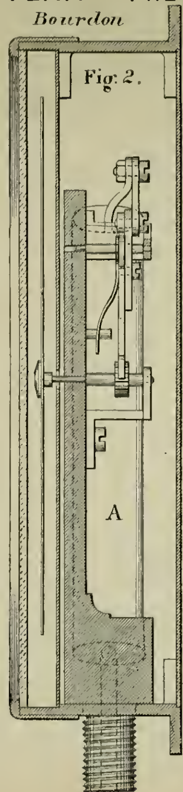
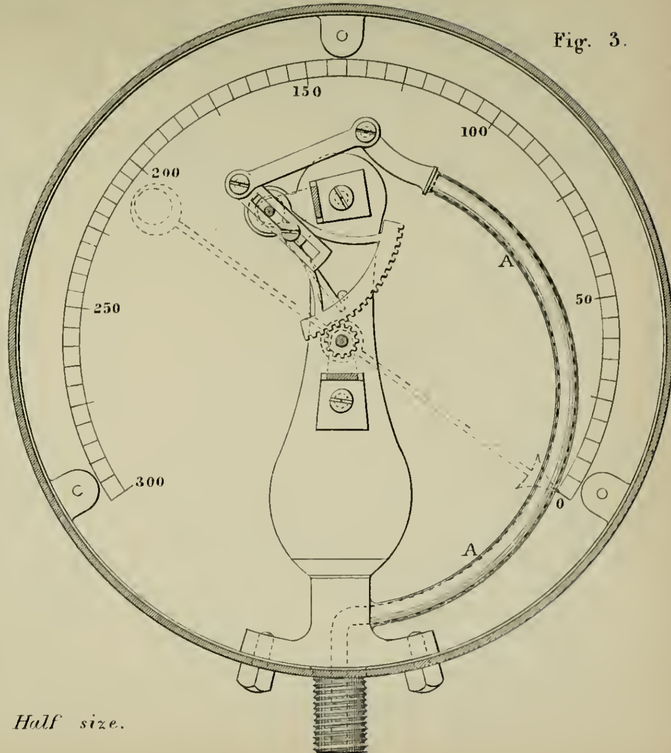


Fig. 3.



Half size.

Fig. 4. *Section of Tube.*
Full size.

(Proceedings Inst. M. E. 1871)

STEAM PRESSURE GAUGES.

Schaeffer Gauge.

Fig: 5.

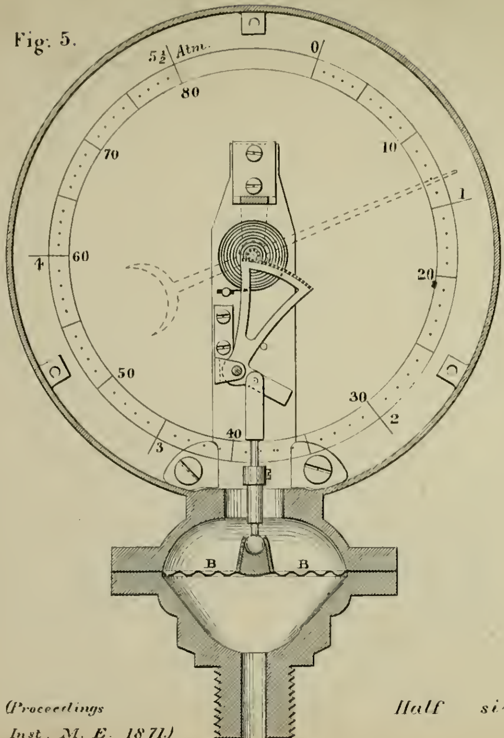
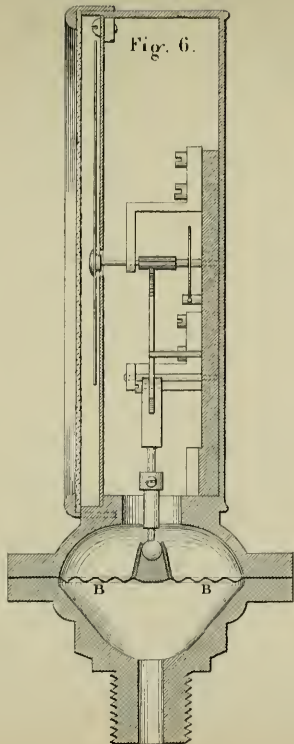


Fig. 6.



Half size.

Fig. 7.

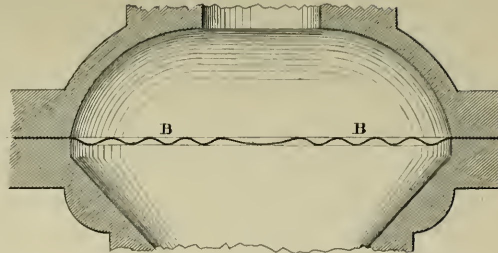
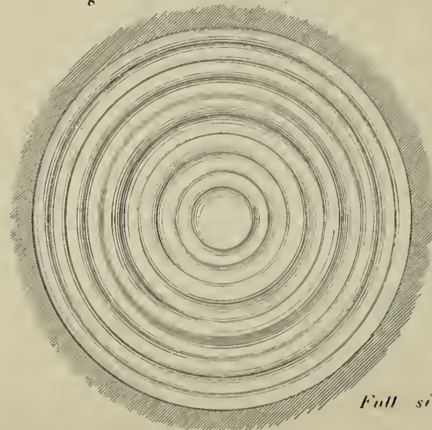


Fig. 8. Plan of Pressure Plate.



Full size.

(Proceedings Inst. M. E. 1871.)

STEAM PRESSURE GAUGES.

Wallis Gauge.

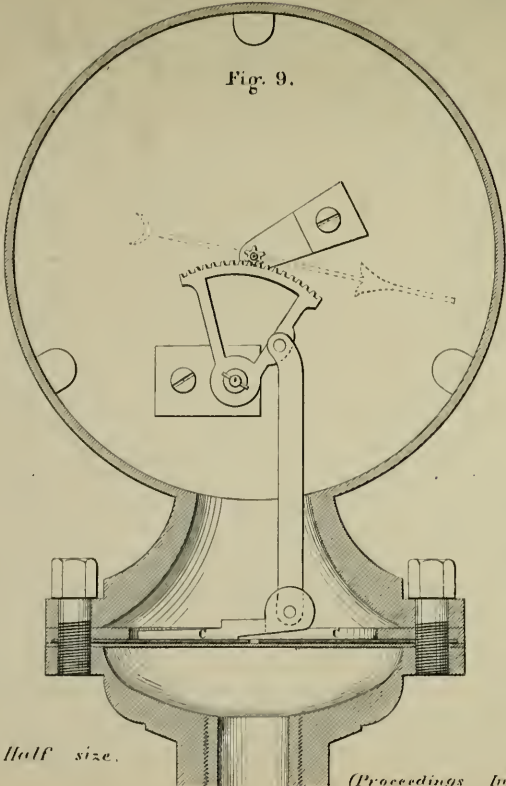


Fig. 9.

Half size.

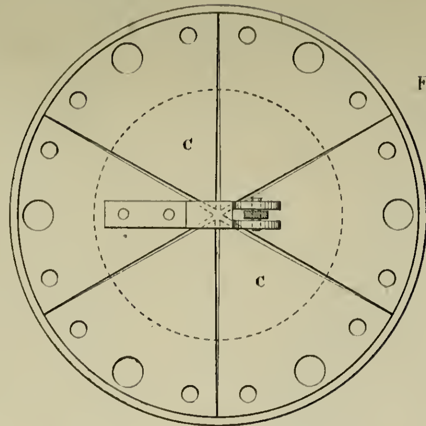


Fig. 10. Plan of Pressure Plate. Half size.

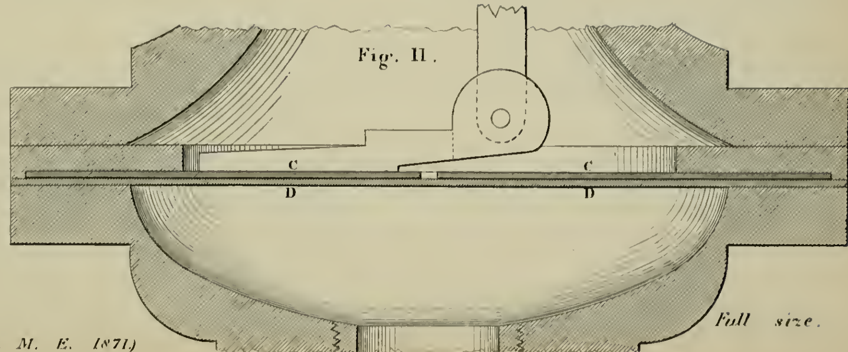


Fig. 11.

Full size.

(Proceedings Inst. M. E. 1871)

STEAM PRESSURE GAUGES.

Miller Gauge.

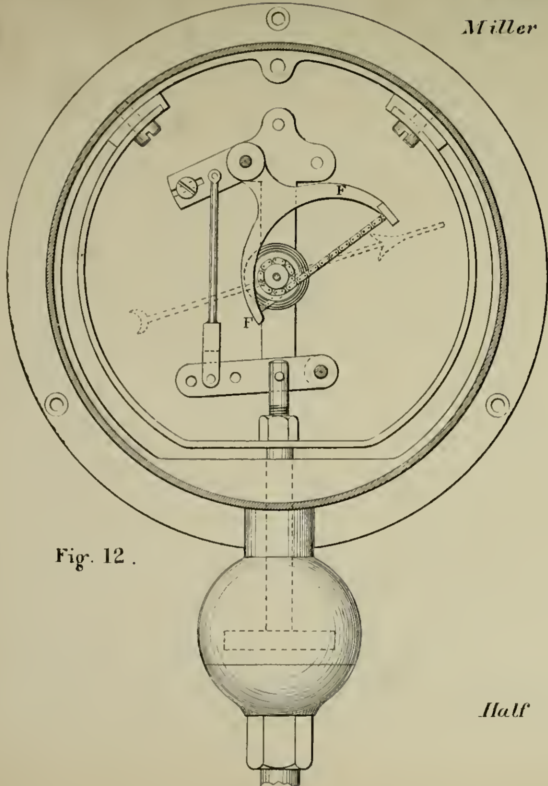


Fig. 12.

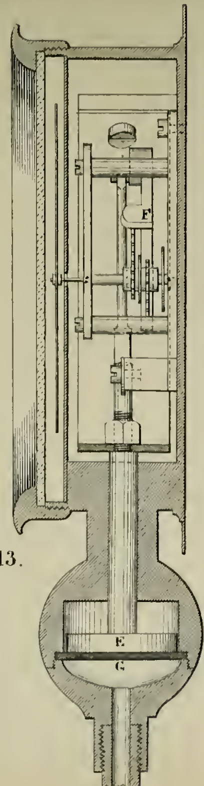
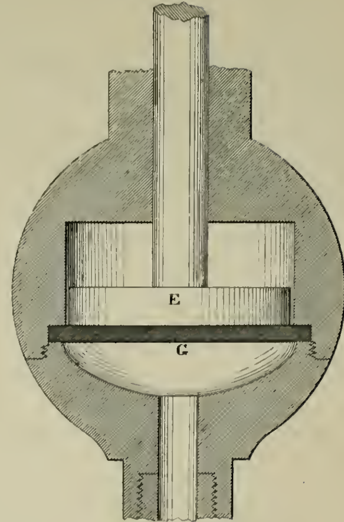


Fig. 13.

Half size.

Fig. 14.



Full size.

(Proceedings Inst. M. E. 1871)

STEAM PRESSURE GAUGES.

Smith Gauge.

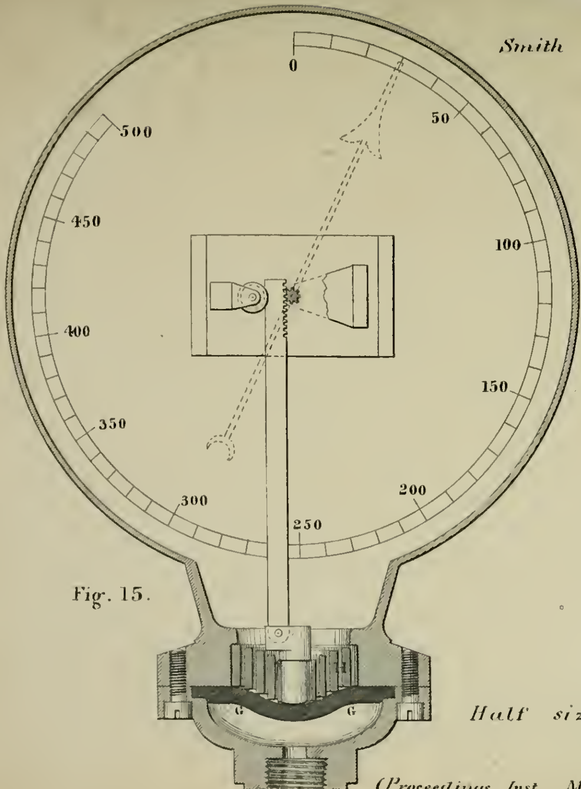


Fig. 15.

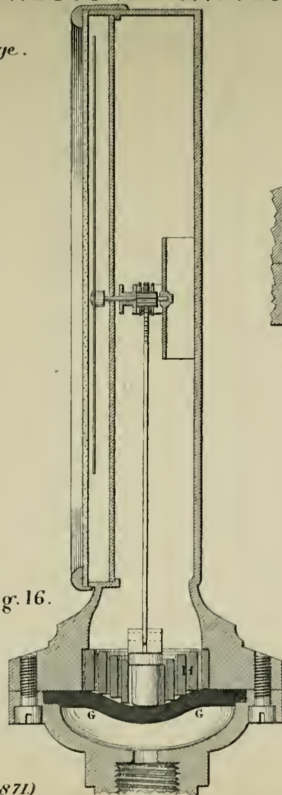


Fig. 16.

Half size.

(Proceedings Inst. M. E. 1871)

Fig. 17.

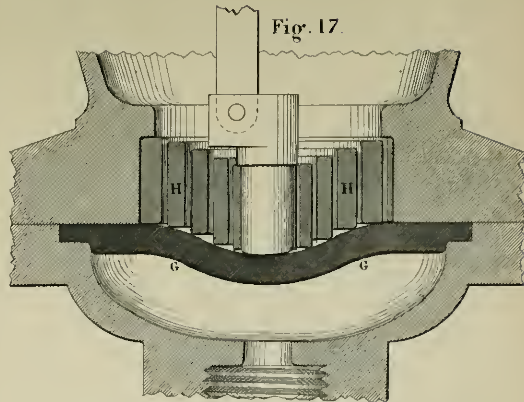
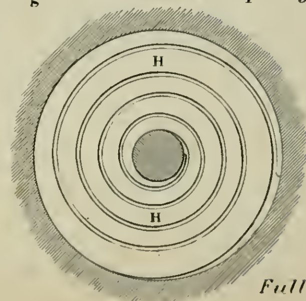


Fig. 18. Plan of Spring.



Full size.

STEAM PRESSURE GAUGES.

Silvester Gauge.

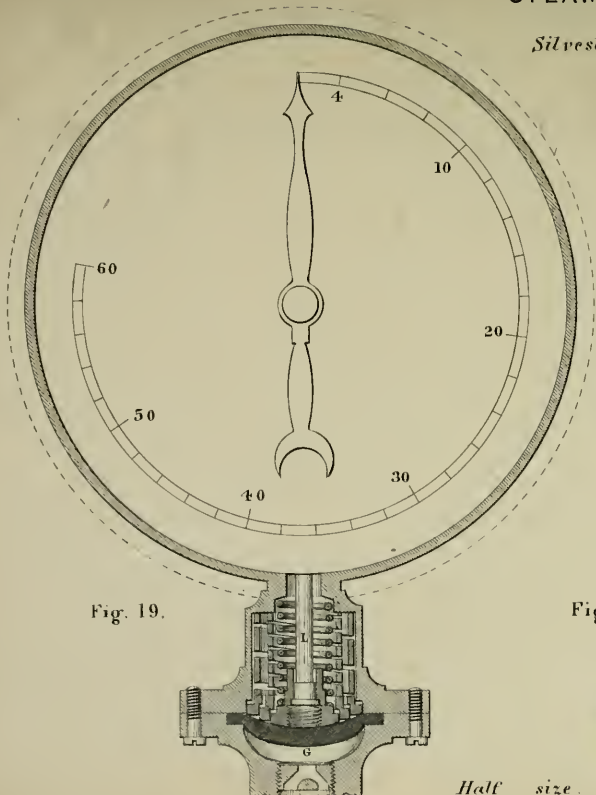


Fig. 19.

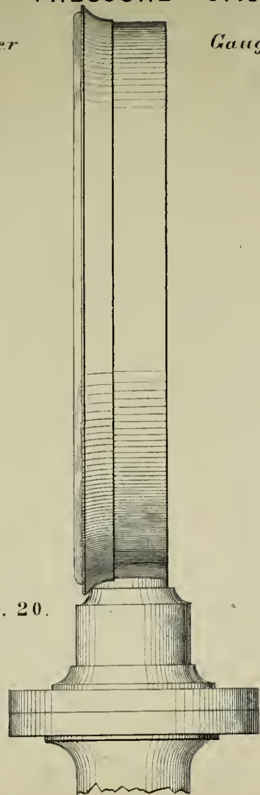


Fig. 20.

Half size.

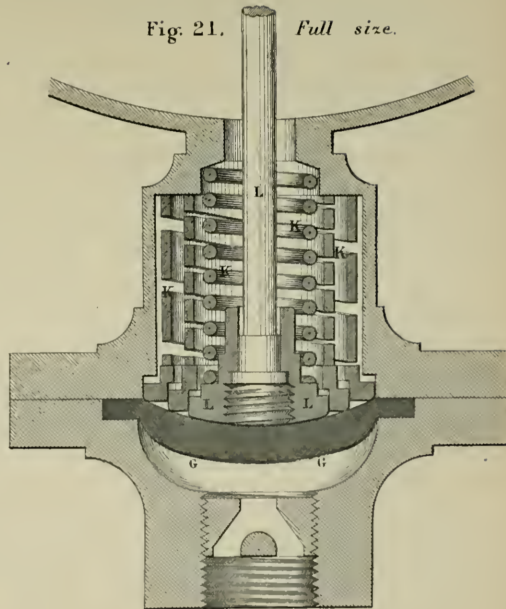


Fig. 21. *Full size.*

STEAM PRESSURE GAUGES.

Foster Gauge.

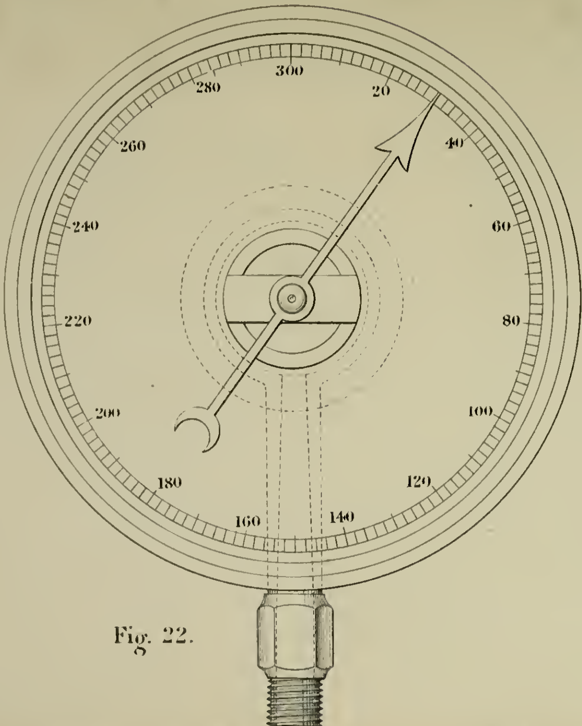


Fig. 22.

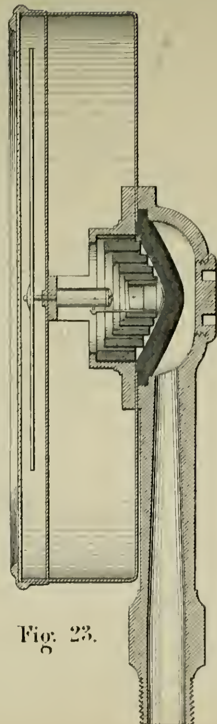


Fig. 23.

Fig. 24.

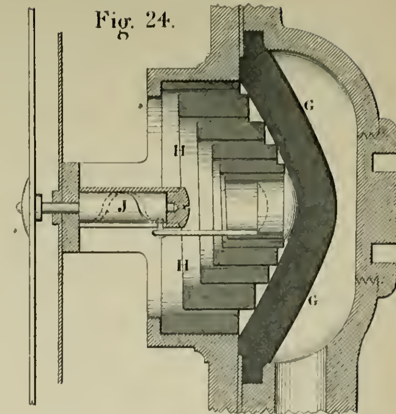
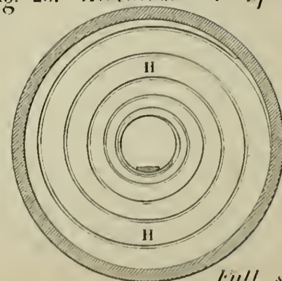


Fig. 25. *Elevation of Spring.*



(Proceedings Inst. M. E. 1871.)

Half size.

Full size.

STEAM PRESSURE GAUGES.

Foster Gauge.

Fig. 26.

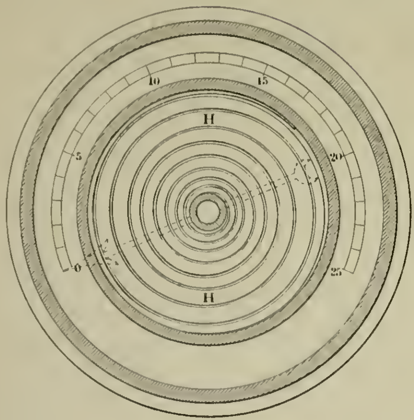
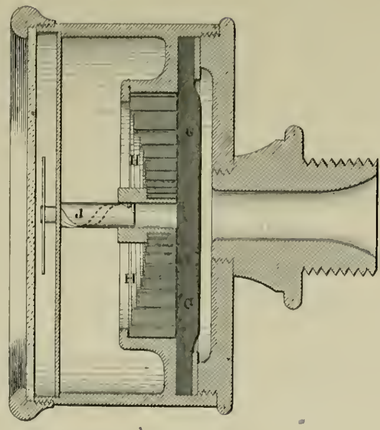


Fig. 27.



Full size.

Fig. 28.

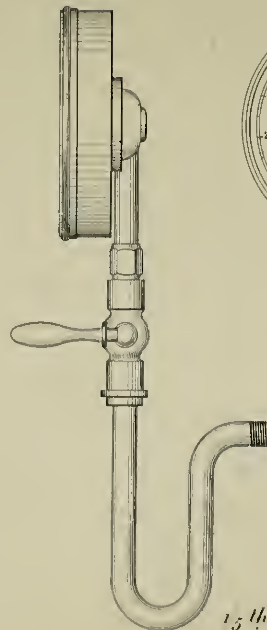
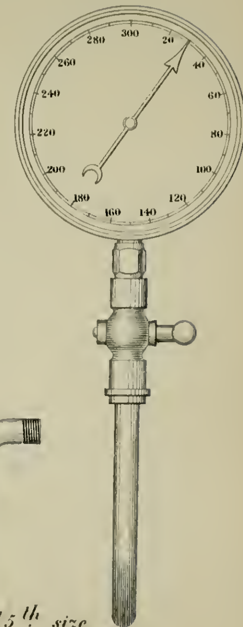


Fig. 29.



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(Proceedings Inst. M. E. 1871.)

PROCEEDINGS.

26 October, 1871.

The General Meeting of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 26th October, 1871; John Ramsbottom, Esq., President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The Chairman announced that the President, Vice-Presidents, and five Members of the Council in rotation, would go out of office in the ensuing year, according to the rules of the Institution; and that at the present meeting the Council and Officers were to be nominated for the election at the Anniversary Meeting.

The following Members were nominated by the meeting for the election at the Anniversary Meeting:—

PRESIDENT.

C. William Siemens, ... London.

VICE-PRESIDENTS.

(Six of the number to be elected.)

I. Lowthian Bell, ... Newcastle-on-Tyne.
Frederick J. Bramwell, ... London.
William Clay, ... Birkenhead.
Charles Cochrane, ... Dudley.
Edward A. Cowper, ... London.
Thomas Hawksley, ... London.
Sampson Lloyd, ... Wednesbury.
William Menelaus, ... Merthyr Tydvil.
John Robinson, ... Manchester.
Charles P. Stewart, ... Manchester.

P 2

COUNCIL.

(*Five of the number to be elected.*)

Charles Edwards Amos,	London.
William Bouch,	Darlington.
John Fernie,	Ventnor.
George Harrison,	Birkenhead.
John Hick, M.P.,	Bolton.
Frederick W. Kitson.	Leeds.
Edward B. Marten.	Stourbridge.
Walter May,	Birmingham.
John Napier,	Glasgow.
Joseph Shuttleworth.	Lincoln

The Chairman announced that the Ballot Lists had been opened, and the following New Members were duly elected :—

MEMBERS.

Joseph Adamson,	Manchester.
James Burrows,	Wigan.
Charles Cabry,	York.
Christopher Fisher Clark,	Newton-le-Willows.
James Cleminson,	London.
Joseph Craven,	Leeds.
William John Forrest,	Ottawa, Canada.
Richard Cadbury Gibbins,	Birmingham.
John Henry Greener,	London.
Alfred C. Hill,	Middlesbrough.
Joseph Hughes,	Manchester.
Charles Henry Jones,	Derby.
William Lee,	Tipton.
James Marshall,	Gainsborough.
Richard David Sanders,	Bombay.
Thomas Wrightson,	Stockton-on-Tees.

ASSOCIATE.

Samuel Marsh,	Nottingham.

The following paper was then read :—

DESCRIPTION OF MILLER'S CAST-IRON STEAM BOILER.

By Mr. JOHN LAYBOURNE, of Newport.

In the employment of steam power the prevailing tendency at the present time is in the direction of a still further increase of steam pressure for all classes of engines, as an important source of economy of fuel; the question of safety in steam boilers consequently becomes one of increasing importance, and economy of fuel does not merely imply the cost of the fuel itself, but is intimately connected with the cost of wear and tear of boilers, cost of labour, and extent of space at disposal. The Cast-iron Boiler designed by Mr. J. A. Miller of Boston, United States, which forms the subject of the present paper, has proved to be a successful application of cast iron for this purpose, and from the experience of $2\frac{1}{2}$ years' working in this country appears to fulfil in a very complete manner the necessary conditions of a thoroughly safe and economical boiler.

This boiler is shown in Figs. 1 and 2, Plates 73 and 74, and is constructed of a series of separate cast-iron sections, joined together at the base of each by flanges and bolts. The sections are of two patterns only, each of comparatively small size, so as to contain only a small quantity of water; those at the front end are ∩ shaped tubes A A, forming a succession of arches over the firegrate, as shown to a larger scale in Figs. 5 and 7, Plates 76 and 78. The rear sections B B consist each of five vertical tubes cast in one piece, as shown in Figs. 6 and 7, united by a transverse horizontal tube at bottom and top, and finished at the top with a flange joint upon which is fixed a cover. The several sections are bolted together at the bottom by flange joints, the front arched sections having two connections, one in each leg, and the rear sections a single connection in the centre; these connections form continuous longitudinal tubes at the bottom of the boiler, which are closed by a flanged cap at each

end, as shown in Figs. 1 and 2. The tubes of the firebox sections are 7 inches diameter inside, and 2 ft. 4 ins. width in the arched opening; the vertical tubes of the rear sections are taper in form, 4 inches diameter inside at bottom and 6 inches at top, and they are 2 ft. 6 ins. length in the vertical portion, with an average of 2 inches clear space between the tubes. The connecting flanges of the rear sections are placed out of centre with regard to the tubes, so that simply reversing the sections brings the spaces of one opposite the tubes of the next, for the purpose of intercepting the flame and heated gases more effectually. The castings are $\frac{1}{2}$ inch thick, and the rear sections weigh about 10 cwts. each, and the front arched sections about 5 cwts. each.

Special provision is made for maintaining circulation of the water in each portion of the boiler. In the front arched sections a longitudinal midfeather is cast in each leg, as shown in Fig. 5, Plate 76, extending nearly to the top and bottom, by which the ascending current of heated water on the inner side exposed to the fire is separated from the descending current of cooler water on the outer side. In the rear sections an internal circulating tube is suspended in each of the vertical tubes, as shown in Figs. 6 and 7, causing the heated water to ascend through the outer annular space, and the cooler water to descend within the circulating tube, which is of cast iron and is held central by snugs cast upon it. The steam is taken off from the top of each of the sections by a 2 inch wrought-iron branch pipe C, Figs. 5 and 6, bent at right angles, and connected to a horizontal cast-iron steam main D, 10 inches diameter, which extends the whole length of the boiler, and is carried outside the brick setting. The branch pipes C C are fixed to each of the sections by a flange bolted to a corresponding flange upon a short neck cast on the top of the section; and they are connected to the steam main D by a flange.

The expansion of the cast-iron sections when heated does not affect the joints, because in the case of the rear sections the separate castings are connected together by only a single joint at the bottom, and are thus free to expand in any direction without injury. In the front arched sections the effect of the expansion is to widen the

arch to the extent of $\frac{3}{8}$ inch; the arched sections are connected to the first of the rear sections, for the purpose of affording a continuous water way through the whole length of the boiler, but this connection is on one side only, so that they are left free to expand and slide upon the brickwork on the other side. The wrought-iron branch steam-pipes C, connecting the sections at the top to the steam main D, spring readily to a sufficient extent to allow for the excess of expansion of the cast-iron sections, without causing any objectionable strain on the joints.

The flange joints of the boiler are all faced and put together simply with wire gauze and red lead, so that they can be readily separated and re-made if required; and they are all finished to a standard template, so that any portion of the boiler can be readily removed and replaced, without disturbing the rest of the sections, which are all duplicates of one another. The front arched sections are all finished to the same length of 11 inches at the bottom joint, and the rear sections to 12 inches length, as shown in Fig. 7, Plate 78. All the joints are completely protected from the action of the fire, and are found to continue thoroughly steam-tight. The bottom connecting joints are all below the level of the fire, those of the front sections being below the firegrate, as seen in Fig. 1, and those of the rear sections are covered by the deposit of dust in the bottom of the flue. The joints at the top are protected by a layer of brickwork which rests upon the castings, as shown in Figs. 5, 6, and 7; and the rear sections are cast with small projecting ribs upon them, which come together when the sections are fixed in their places, thus forming a close top to the flue, as shown in Fig. 7. The whole boiler is enclosed by side walls of brickwork, which are carried up above; and the top is covered in with loose cast-iron plates that are readily removed for inspection, as shown in Figs. 1, 5, and 6. A large sight-hole with cast-iron cover-plate is made in one side wall opposite every alternate rear section, as shown in the plan, Fig. 2, which allows of cleaning all the surfaces of the cast-iron tubes from soot and dust by means of a jet of steam introduced by a flexible pipe into each of the holes in succession; this cleaning is usually done about every other day.

A blow-off cock E, Fig. 1, is fixed on the front end of each of the two bottom side tubes, by means of which all sediment forming in the boiler is regularly blown out at frequent intervals; the boiler is usually blown off completely once a week, and a small portion of the water is also blown off three times in each week. Any deposit accumulating in the bottom portions of the boiler can be raked out whenever necessary, by taking off the bottom flanged covers at the ends of the boiler. The feed water is introduced at the bottom of the boiler at F F, Figs. 2 and 6, below the fire level; the feed pipe is connected to the bottom main on one side of the fire and also to the first of the rear sections. The experience of the continuous working of the boiler for $2\frac{1}{2}$ years has shown that, when it is periodically blown out under pressure, sediment does not injuriously collect in any of the parts that are exposed to the heat of the fire or flue; and the crowns of the front arched sections, which are exposed to the direct action of the fire, are found to keep completely free from scale. In one of these boilers however which was not blown off for a period of seven months, and during that time was kept at work almost constantly day and night, the first of the rear sections became entirely choked with scale in all the vertical tubes except one, and a crack took place in that one tube at the point G in Fig. 6, Plate 77. The fracture being in cast iron had a clean sharp edge in this instance, as well as in the other cases of fracture that have occurred with the boiler. The water escaped through the crack, and the steam pressure was liberated, without any other injury arising, and without any of the brickwork being displaced.

The cast iron bears the heat of the fire without injury, because the steam is carried off as quickly as it is generated, and an efficient circulation of the water is constantly maintained, so that the metal of the tubes exposed to the fire is protected by having solid water always in contact with its surface. The boiler has been applied to balling and re-heating furnaces at ironworks, as shown in Figs. 3 and 4, Plate 75, and appears to stand their great heat without injury.

The size of the boiler is regulated by the number of sections employed in its construction; and more sections can be added

afterwards at any time, if desired, without disturbing those previously fixed. The usual size of the boiler, as shown in Figs. 1 and 2, Plates 73 and 74, consists of six arched front sections and twelve rear sections, and is equal to about 36 horse power. The effective heating surface of each rear section, taken from the top of the base piece at H to the centre of the upper chamber at K in Fig. 6, is 23 square feet, which is considered equivalent to 2 horse power; and the effective surface of each arched section above the firegrate level, taking only the inner half of the surface, is 7 square feet, which is also considered equivalent to 2 horse power.

At the writer's works, Isca Foundry, Newport, where the first of these cast-iron boilers was erected in this country, the same machinery had previously been driven by a Lancashire boiler of 26 feet length and 6 feet diameter with two flue-tubes of 2 feet diameter, the firegrate area being 27 square feet, and the total heating surface 390 square feet. The cast-iron boiler used in its place has eight arched sections and fourteen rear sections, giving a heating surface of 378 square feet, and the firegrate area is 17 square feet. The result of a careful trial extending over ten days to test the relative consumption of the two boilers, including in each case the fuel required to get up steam, was that the average total consumption of fuel per day was 16 cwts. with the cast-iron boiler and 27 cwts. with the Lancashire boiler, the day's work being practically the same for each boiler. The coal used was Monmouthshire small steam-coal, costing 6*s.* per ton at the boilers; and the difference of cost in working was consequently very considerable.

In trials made to ascertain its evaporative power and economy, the cast-iron boiler has proved very satisfactory; and in one instance an evaporative duty was obtained as high as 11½ lbs. of water per lb. of coal. In this case 625½ gallons of water at 53° Fahr. were evaporated in 3 hrs. 54 mins. by 560 lbs. of Ebbw Vale Elled coal, amounting to 11·17 lbs. of water per lb. of coal, and equivalent to 11·67 lbs. of water evaporated from 100° standard temperature of feed; the steam pressure was from 55 to 60 lbs. per inch.

In the appended Table I are given the particulars of a series of experiments made upon the evaporative duty of the cast-iron boiler at the writer's works, with three kinds of South Wales coal. The general results were that the evaporative duty ranged from 10·15 to 11·67 lbs. of water per lb. of coal, calculated at the standard temperature of feed of 100° Fahr.,* the mean evaporative duty being 10·93 lbs.; and the rate of evaporation per square foot of grate per hour ranged from 79 to 119 lbs. of water; the maximum temperature in the chimney flue did not exceed 425°, and the firebars had $\frac{1}{4}$ inch spaces between them.

In a subsequent series of experiments made upon the same boiler by Mr. Joseph Tomlinson, with other kinds of South Wales coals, for the special purpose of testing the speed of evaporation and the total evaporative power of the boiler, the evaporative duty ranged from 9·37 to 10·15 lbs. of water per lb. of coal, the mean being 9·82 lbs.; and the rate of evaporation per square foot of grate per hour ranged from 136 to 159 lbs. of water; the maximum temperature in the chimney flue was 575°, and the firebars had $\frac{1}{2}$ inch spaces. The particulars of these experiments are given in Table II appended.

One of these boilers that had been working continuously for $5\frac{1}{2}$ months at the City Saw Mills, Worcester, has recently been opened for the first time since it was put to work, and the state of the interior carefully examined, and the whole deposit raked out. There was found to be only a small quantity of loose scale and mud in the bottom horizontal tubes, 10 lbs. in weight, and consisting of thin scale of less than 1-16th inch thickness; and the interior surface of the cast-iron sections was found to be quite clean. Their outer surface where exposed to the fire was also found to be quite sound, and the metal uninjured. This boiler, which is of the size

* The equivalent evaporation from 100° Fahr. standard temperature of feed is calculated by the following Admiralty formula employed for the purpose in the Wigan coal trials in 1866-67, the latent heat of steam at atmospheric pressure being taken at 988° Fahr.:—

$$\text{Lbs. of water actually evaporated} \times \frac{988^\circ + 100^\circ \text{ standard}}{988^\circ + \text{temp. of feed}} = \left\{ \begin{array}{l} \text{Lbs. of water evaporated} \\ \text{from } 100^\circ \text{ standard temp.} \end{array} \right.$$

shown in Fig. 1, Plate 73, had been supplied with water-works water, and had been completely blown off under steam pressure every week regularly, and refilled again at once from the main; it had also been partially blown off twice a week to the extent of 2 inches depth of water.

This construction of boiler, although not incapable of being injured through carelessness or ignorance, is considered with ordinary care in working to be free from any risk of a destructive explosion taking place. This the writer thinks has been fully proved by the result of the three fractures that have taken place in his experience, one at the point G in Fig. 6, as already described, and two at the bottom corner J J, Fig. 2, where the last of the arched sections is attached to the first of the rear sections; in each instance the result was simply the escape of the water from the boiler through a fracture in one of the cast-iron sections, without any other damage being caused. In one of these cases the whole of the water contained in the boiler, amounting to 500 gallons, was discharged in three minutes, with only the effect of putting the fire out.

This boiler has the advantage of allowing any portion to be readily removed and replaced, without disturbing any other portions, by simply disconnecting the joint on each side at the bottom of the section to be removed, and the steam pipe at the top. Access is obtained for this purpose by removing a portion of the brickwork at one side, opposite to the section that has to be taken out, which is then disconnected and drawn out at the side, the whole process of removal and making good again being effected in twenty-four hours. The brickwork setting of the boiler is of very simple description, consisting only of the longitudinal side walls, with low cross-walls to support the separate sections, as shown in Figs. 1 and 2.

As the total quantity of water contained in this boiler is small in proportion to the extent of heating surface, a range of 9 inches in the gauge glass giving a capacity of only 100 gallons, it is requisite in ordinary working that the water level and the feed should be attended to regularly at intervals not longer than twenty minutes. In order to avoid the necessity for this constant attention, it has been

TABLE I.

Experiments upon Evaporative Duty of Miller's Cast-iron Boiler at the Isca Foundry, Newport, with Monmouthshire Steam Coals.

Date of Experiment.	Description of Coal.	COAL BURNT per sq. foot of grate per hour.	Pyrometer in flue beyond boiler. Highest reading.	Actual Temperature of Feed.	WATER EVAPORATED. Calculated from Actual temperature of Feed.			WATER EVAPORATED. Calculated from 100° Fahr. standard temp.		
					Per lb. of coal.	Per hour.	Per sq. foot of grate per hour.	Per lb. of coal.	Per hour.	Per sq. foot of grate per hour.
		Lbs.	Fahr.	Fahr.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1869. Sep. 9	Tredegar Large Coal . .	7·65	......	70	10·12	1316	77·41	10·40	1352	79·58
,, 16	Ebbw Vale Elled . . .	8·45	......	68	10·52	1512	88·94	10·83	1557	91·63
Nov. 15	Do. . . .	8·44	360	53	11·17	1604	94·35	11·67	1676	98·60
,, 24	Abercarn Top	10·32	400	56	9·74	1710	100·59	10·15	1781	104·82
,, 25	Abercarn Bottom . . .	8·60	350	56	10·81	1580	92·94	11·26	1646	96·85
1870. Feb. 5	Ebbw Vale Elled . . .	10·67	425	45	10·58	1921	113·00	11·14	2023	119·01
,, 22	Tredegar Small Coal . .	9·88	375	48	10·52	1768	104·00	11·05	1856	109·21

In these experiments the space between the firebars was $\frac{1}{4}$ inch. Area of firegrate 17 square feet.

TABLE II.

Experiments upon Speed of Evaporation and Total Evaporative Power of Miller's Cast-iron Boiler at the Isca Foundry, Newport, with Cardiff Steam Coals.

Date of Experiment.	Description of Coal.	COAL BURNT per sq. foot of grate per hour.	Ash and Clinker	Pyrometer in flue beyond boiler. Highest reading.	Actual Temperature of Feed.	WATER EVAPORATED. Calculated from Actual temperature of Feed. Per lb. of coal.	Per hour.	Per sq. foot of grate per hour.	Calculated from 100° Fahr. standard temp. Per lb. of coal.	Per hour.	Per sq. foot of grate per hour.
1870.		Lbs.	Per cent.	Fahr.	Fahr.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
May 24	4 ft. Vein	15·47	4·0	500	56	9·27	2441	143·59	9·67	2544	149·63
„ 25	9 ft. Vein	16·47	4·0	500	56	9·26	2594	152·58	9·66	2703	159·00
June 17	4 ft. Vein	16·77	4·5	550	67	9·09	2592	152·47	9·37	2673	157·24
„ 22	Locomotive Coal . .	15·82	6·6	525	69	9·35	2514	147·88	9·62	2587	152·20
July 7	Steam Vein (light firing)	14·00	4·8	525	67	9·85	2346	138·00	10·15	2419	142·32
„ 13	Do. (hard firing)	15·48	4·7	550	70	9·64	2539	149·35	9·90	2611	153·59
„ 14	4 ft. Vein	15·19	4·7	550	70	9·85	2543	149·59	10·12	2615	153·83
Dec. 13	Two Veins mixed . . .	13·53	4·4	575	44	9·56	2200	129·41	10·08	2320	136·44

In these experiments the space between the firebars was ½ inch, and the fire was not disturbed with the pricker, only the shovel being used for firing. Area of firegrate 17 square feet.

found advantageous to employ the self-acting feed apparatus shown in Fig. 6, and to a larger scale in Fig. 8, Plate 79. This apparatus, the invention of Mr. Berryman, consists of a hollow cast-iron ball M, suspended from the end of a counterpoised lever L, which oscillates on knife-edges like a scale beam; two $\frac{1}{2}$ inch pipes communicate respectively with the top and bottom of the ball, the former terminating at the high-water level inside the boiler, and the latter at a lower level. These two pipes extend horizontally for such a distance from the ball as will give sufficient elasticity to allow a short upward and downward motion of the ball. The counterpoise on the lever L is adjusted so as to raise the ball when empty, but to allow it to drop when filled with water; and the lever is connected to the feed-cock N, so as to open the cock when the ball rises, and close it again when it drops.

When the water level of the boiler is below the orifice of the upper pipe, the ball M is filled with steam, and is in its top position, opening the feed-cock for supplying the boiler; but when the water rises above the orifice of the upper pipe, the steam previously contained in the ball is cut off from the boiler and becomes condensed by its continued exposure to the atmosphere, and the ball is then filled immediately with water entering from the boiler, and the increase of weight causes it to drop and thereby shut off the feed. When the water level falls again below the orifice of the upper pipe, the steam enters there, and the ball becomes emptied by the water running back into the boiler; the counterpoise upon the lever then raises the ball, and opens the feed-cock again for supplying the boiler.

The lever L can be set to act on the steam valve of a donkey pump, so as to regulate the working of the pump for feeding the boiler; but where several boilers are supplied from one pump, it is preferable for each boiler to be provided with a separate apparatus and feed cock, and to keep the pump constantly at work, the surplus supply of water being allowed to pass through an escape valve into the suction pipe.

Mr. Laybourne exhibited a specimen of a vertical pipe which had purposely been cut out recently from one of the rear sections in the cast-iron boiler at his own works, after having been $2\frac{1}{2}$ years in use in the fourth section from the fire; the metal was found to show no signs whatever of deterioration after working continuously during that period. He showed also a similar specimen of a vertical pipe cut from the first of the rear sections, having a horizontal crack across the middle on the side facing the fire, at the point G in Fig. 6; this had been taken out of a boiler which had been kept seven months in nearly constant work without blowing off. A specimen was also exhibited of the fractured base of the hindmost arch-tube from one of the early boilers, where the bottom of the legs had been bolted to the rear section on each side of the fire, so that the legs had been prevented from expanding freely sideways; and consequently when the arch tubes expanded under the heat, a strain was thrown upon these two connections, causing one of them to give way by fracture of the casting at the point J in Fig. 2; on this account the connection of the arch tubes to the first rear section was now made on one side only of the fire, the legs being left free at the other side to yield laterally to the expansion of the arch.

Mr. C. Cochrane said he had recently examined the cast-iron boiler at Worcester that had been mentioned in the paper, and on trying the metal with a file where exposed to the action of the fire he had found it quite bright and altogether uninjured; a slight touch with the file was sufficient to remove the external skin and disclose the bright metal. In other cast-iron boilers that he had seen tried in the north of England the metal had become so seriously injured by its exposure to the fire as to lead to the total abandonment of the boilers; and in the present instance therefore he had been much surprised at finding so little appearance of any injurious action by the fire upon the cast iron. This construction of boiler certainly seemed to him to give every promise of proving a successful application of cast iron for the purpose; and he thought it only needed a little further experience to show that cast iron could be used for steam boilers with as much success as had hitherto attended wrought-iron boilers, and with the small water-spaces there was the

great additional advantage of security from the disasters of explosions. He fully concurred in the explanation which had been given of the fracture in the base casting exhibited from one of the arch tubes in the cast-iron boiler now described, as it was clear that, when the legs of the arch tubes were bound, by being bolted to the first rear section on both sides of the firegrate, a severe strain must be thrown upon those two places of attachment by the expansion of the arch tubes, and one of the two corners must ultimately be fractured across, as had been the case in the specimen exhibited. The present plan of making the attachment on one side only of the boiler, and leaving the other side free to expand outwards, obviated all difficulty.

Mr. J. Tomlinson remarked that the special object of the experiments which he had made (given in Table II) had been to ascertain the speed of evaporation that could be obtained with the cast-iron boiler, and the evaporative power when heavily fired; and the results he thought were highly satisfactory, as regarded both the rate of evaporation and the evaporative duty, the latter ranging from 9·37 to 10·15 lbs. of water per lb. of coal, and the speed of evaporation from 136 to 159 lbs. of water per square foot of grate per hour; the firing was done entirely with the shovel, and no attempt was made to urge the fires unduly by stirring them with a pricker. The result of firing more heavily was seen to be a nearly proportionate increase in the rate of evaporation, but a reduction in duty. The coal used was ordinary Welsh coal, that in the first two experiments being from the same colliery in the Rhondda Valley, while that in the third was from another part of the valley; the locomotive coal used in the fourth experiment was the Bastard Steam Coal, also from the Rhondda Valley, which had been employed in some of the locomotive experiments that he had described in a paper at a former meeting of the Institution (see Proceedings Inst. M. E. 1858 page 284).

The cast-iron boiler now described he considered would for many purposes be found to be a great improvement upon the large wrought-iron boilers generally employed, and there was no doubt it would be particularly advantageous for confined situations in towns,

on account of the much smaller space that it occupied, and its safety from explosion. He had himself had experience of some of the fractures that had occurred in the cast-iron sections, and was satisfied that no dangerous results could ensue in such cases. There was still room however for improvement, he thought, in the construction of the boiler, as the 2-inch spaces for the passage of the flame between the pipes in the several sections of the boiler appeared to him to be too small; and he considered if they had been increased to $3\frac{1}{2}$ inches or more, the results of the experiments would have been better, in consequence of more heat being allowed to reach the sections furthest from the fire, as he had not been able to get the temperature in the chimney flue above about 550° Fahr., even with hard firing. He had had no trouble in getting the boiler fed regularly with an injector during the experiments. With regard to the circulating tubes adopted in all the sections of the boiler, he had strong doubts as to their utility, and thought the boiler would probably work as well without them; at any rate he considered they should be made much smaller than they were, inasmuch as the present annular space of only $\frac{1}{2}$ inch outside the circulating tubes seemed to him likely to be in great danger of becoming choked with deposit, which would certainly result in fracture of the cast-iron pipes.

Mr. E. B. Marten said he had seen the cast-iron boiler at Worcester, and had been much pleased with the complete way in which the whole of the details had been worked out. As now constructed it appeared to him to be a great improvement upon the original construction brought out in America, particularly in respect to the alteration of liberating one end of the horse-shoe shaped pipes over the fire, so as to allow of their expanding freely. Although sharing the feeling of distrust which was generally entertained at present with regard to the use of cast iron for steam boilers, he wished to state that he had not been able to detect the slightest alteration in the appearance of the metal of the boiler at Worcester, on examining it by means of the file.

The President enquired how many of these boilers were now at work, and what space they occupied in comparison with ordinary boilers.

Mr. Laybourne replied there were now about thirty of the boilers at work in this country, of which as many as eight were in use at the Abercarn Tinplate Works at Abercarn in Monmouthshire, all on puddling and balling furnaces; at other works also they were working in connection with puddling and balling furnaces, and several were fired in the ordinary way at manufactories. The space occupied by these cast-iron boilers was only about 40 per cent. of that with ordinary wrought-iron boilers of the same power.

Mr. T. Hawksley asked what was the comparative cost of the cast-iron boiler per horse power.

Mr. Laybourne said the cost was about the same as that of a Cornish boiler to do the same work, as the castings were expensive to make, and there was so much fitting to be done in putting them together in the boiler.

Mr. C. Cochrane enquired whether any special mixture of metal was used for the castings forming the boiler.

Mr. Laybourne replied that a mixture of strong Welsh with soft Scotch iron was preferred for the castings, great care being taken to pour the metal into a large well or gate, so that the time required to fill the mould should be shortened as much as possible; by this means the occurrence of "cold shuts" by the chilling of any portion of the metal was avoided. Each section was proved by hydraulic pressure to 500 lbs. per square inch, before any work was done to it. Irregularity in the thickness of the metal in different parts of the castings was immaterial, provided the supply of water was properly maintained in the boiler while working; it was only in the event of low water in the boiler that there would be any risk of thin places being found out and fractured by the expansion.

The President enquired whether the cast-iron boiler was worked at higher pressures of steam than that named in the paper of 55 to 60 lbs. per square inch.

Mr. Laybourne replied that the steam pressure in the boiler at his own works was generally from 80 to 90 lbs. per square inch, and the safety-valve was set to blow off at 120 lbs. Except at meal times it was very rare to see any steam blowing off at the safety-valve, so that there was no waste of steam in that way. The

boiler had been proved by water pressure up to 200 lbs. per square inch.

Mr. J. Tomlinson said that in his experiments upon the boiler he had frequently had the steam pressure up to 145 lbs. per square inch.

Mr. R. H. Taunton asked whether there had been more incrustation or less in the cast-iron boiler than in wrought-iron boilers under similar circumstances of working.

Mr. Laybourne considered the quantity of incrustation was about the same in proportion to the quantity of water evaporated, and it was effectually got rid of by the frequent and regular blowing off. When this was properly attended to, no scale formed in the tubes upon the sides directly exposed to the fire, as the constant current of water and steam over those surfaces prevented the deposit from settling there; and that which adhered to the surfaces that were not exposed to the fire was found to scale off of itself, and collected in the bottom horizontal pipes, from which it was blown out at the next time of blowing off.

Mr. E. B. Marten enquired whether any difficulty had been experienced from priming with the cast-iron boiler.

Mr. Laybourne said he had not found any liability to priming, except when working with brackish water.

Mr. F. B. Vallance asked what length of time was required for getting up steam from cold water in the cast-iron boiler. He thought there must be a great deal of heat absorbed by the thickness of the metal as compared with a wrought-iron boiler; though, on the other hand, there was the advantage of a smaller quantity of water to be heated in the cast-iron boiler.

Mr. Laybourne replied that steam was easily got up in an hour from the time of filling the boiler with cold water.

The President enquired whether the cast-iron boiler could be filled up again with cold water immediately after blowing off, without risk of injury by fracture of the pipes; and whether it was likely the crack exhibited might have been produced in that way.

Mr. Laybourne said the boiler was usually filled at once with cold water after blowing off, and no injury had resulted from this cause in any instance. The fracture in the specimen exhibited of one of

the vertical pipes had been occasioned he believed solely by the choking of the adjacent pipes in that section of the boiler, in consequence of its having been worked continuously for seven months without blowing off; the choked pipes having therefore become more heated by the fire had expanded vertically to a greater extent, and this one pipe not being hot enough to stretch so much had necessarily been relieved by cracking transversely under the strain thrown upon it by the other pipes in the section.

The PRESIDENT enquired what was the greatest length of time that any of these cast-iron boilers had been at work.

Mr. LAYBOURNE replied that two years and a half was the longest time he had had any of the boilers at work; the boiler at his own works had now been in use that length of time, and the specimen pipe now exhibited from it showed that the metal continued uninjured after constant exposure to the fire throughout that period.

Mr. R. WILLIAMS observed that the experience of the use of cast-iron for the bridges and sides of puddling furnaces did not appear to him to be favourable to its application for steam boilers. In those cases the castings were hollow and were cooled by a current of water constantly maintained through them, the circumstances being thus somewhat similar to those of a boiler, except that the heat was greater and the quantity of water less in the castings; but they were found to burn out very fast, and this certainly led him to doubt the durability of the metal in a cast-iron boiler. Much longer experience than two years and a half seemed to him to be requisite for satisfactorily establishing the durability of such boilers; and he feared that, when worked in connection with puddling furnaces, they would be found utterly useless after only a few years' work. In addition to economy of fuel, perfect safety was wanted, so that a boiler in a forge might be worked for a number of years with complete confidence; and in such situations he thought there would be some danger in using a boiler made up of so many separate pieces put together with joints.

Mr. E. B. MARTEN mentioned that the four-furnace upright boilers first constructed by Mr. Rastrick in South Staffordshire had originally been made of cast iron, and had been given up, not because

the cast iron would not stand the heat, but because of the difficulty of keeping the joints tight, in consequence of the unequal expansion of the tubes and shell.

Mr. J. Tomlinson thought the case was very different with the present cast-iron boiler, in which all the sections were allowed to yield freely to expansion or contraction, without throwing a strain upon any of the joints; whereas in the old cast-iron boiler just referred to, the parts were bolted together in such a manner as to interfere with their expansion, and the bolts and joints were exposed to the flame. In balling or puddling furnaces it was possible that the excess of oxygen might have a more destructive effect upon a cast-iron boiler; but in ordinary furnaces it had been found by the experience to the present time that very little oxidation of the metal took place.

Mr. Laybourne observed that the coating of soot and dust which formed upon the surfaces of the cast iron served also in a great measure to protect it from any injurious action of the flame; and from the fact that the metal had stood two and a half years' constant work without suffering any perceptible deterioration, it seemed reasonable to infer that it might be relied upon to stand for many years longer with perfect safety. It should also be borne in mind that, even in the event of any portion of the boiler giving way, experience had shown that no destructive explosion took place, but the water was simply discharged within the brickwork casing of the boiler without any damage being done.

Mr. C. Cochrane remarked that the soundness of the metal in the cast-iron boiler after the two and a half years' working was seen in the specimen now exhibited, in which the iron was found to be clean and uninjured when the coating of soot was scraped off.

Mr. R. Williams thought that, in the application of the cast-iron boiler to a puddling furnace, the danger of any failure would arise from the risk of the water discharged from the boiler finding its way into the furnace; he presumed the water would not run out of the boiler quietly, but would be discharged with violence in consequence of the pressure of steam inside the boiler, and it appeared to him possible that a jet of water might get thrown into

the puddling furnace, which would certainly be attended with much danger.

Mr. Laybourne said that in the event of a fracture occurring on the side of the boiler nearest to the puddling furnace, the water discharged would be caught in the well that was provided between the boiler and the furnace, as shown in the drawing (Fig. 3), and would all run off into the chimney flue at the side, without getting into the furnace at all. It would take some minutes for the boiler to empty itself through such a crack as that in the fractured specimen exhibited ; and in the instance of a puddling furnace where one of these boilers was at work and a crack had occurred, the man working at the furnace knew nothing of it until finding the steam was blowing back into the furnace and the pressure was going down. Further experience of the cast-iron boiler he was confident would lead to its safety being generally recognised.

The President thought the cast-iron boiler now described was a very fair attempt in the direction of using higher pressures of steam with greater safety than hitherto, and there was no doubt that for such a purpose the subdivision of the water into small portions was the correct principle. How far cast iron was a suitable material for such boilers was a question which did not appear to be as yet satisfactorily settled ; but the present mode of applying that metal for boilers seemed to him to be a very considerable improvement over previous attempts, and well worth watching as to the results of further working, which he hoped would prove more successful than in other cases of cast-iron boilers. The great aim at the present time was to work at higher pressures of steam than were possible with the large boilers hitherto in use ; and any attempt in that direction appeared to him to be deserving of encouragement, on account of the economy and other advantages attending the use of the higher pressures.

He proposed a vote of thanks to Mr. Laybourne for his paper, which was passed.

The following paper, communicated through Mr. Charles Cochrane of Dudley, was then read :—

ON STEAM PRESSURE GAUGES.

By Mr. ERNEST SPON, of London.

An important subject of enquiry in relation to the effective working of steam boilers is the reliable construction of Steam Pressure Gauges, as the defects that are found to exist in their action seriously endanger the safety of boilers, which in some cases have been overstrained and have even exploded in consequence of the erroneous indications of pressure gauges. The inaccuracy of a great number of the pressure gauges in ordinary use has been specially referred to in the reports of the various Boiler Insurance Associations, in which it has been stated that some gauges are found to be defective even when new, and that others rapidly become unreliable when in constant use. A number of pressure gauges on steam boilers have been examined, proved to 50 lbs. pressure, and reported upon at the annual exhibitions of the Royal Agricultural Society; and the result in the last three years was that only 37 gauges were found to be correct out of 265 examined, so that but one seventh of the whole number were correct, the errors of the other gauges ranging from 16 per cent. below to 20 per cent. above the correct indication of pressure.

The Mercurial gauge, consisting ordinarily of a column of mercury supported in a glass tube, was the first form of pressure gauge employed for steam boilers, and is still the most reliable when correctly graduated. It is however subject to such accidents as the mercury being blown out of the tube by negligence in use; and it is very inconvenient for indicating pressures above 30 lbs. to the inch, on account of the height of column necessary. The other contrivance that has consequently been generally adopted as a pressure gauge measures the pressure of steam by the deflection of springs of

different kinds; and a spring being practically uniform in the ratio of its deflection to the force applied, and admitting of a compact construction of gauge, is when properly applied very effective and suitable for measuring steam pressure, as well as pressures of other kinds.

The Bourdon gauge is the most extensively used spring pressure-gauge, and has now been upwards of twenty years in use. The ordinary form of this gauge is shown in Fig. 1, Plate 80, and consists of a curved metallic tube A, oval or flat in transverse section, as shown full size in Fig. 4, which is closed at one end and communicates with the steam pipe at the other end. This elastic tube, when subjected to internal pressure, becomes less curved in consequence of the fluid within the tube pressing equally in all directions; and the outer side of the curved tube being longer than the inner side, the area under pressure on the outer side is greater, so that the total pressure is greater on the outer than on the inner side, and this difference of pressure acts to straighten the tube. The resulting movement of the free end of the tube communicates rotary motion to the index upon the dial, through the intervention of a lever or a toothed sector and pinion, the extent of the motion depending upon the pressure acting within the elastic tube. In order to ensure accuracy, the positions of the graduations on the dial are required to be ascertained in each case by trial with a standard gauge; but this precaution is not always taken, and in many cases the graduations have been marked from the dial of another gauge supposed to be similar in strength of spring. This construction of gauge is subject to the objection that the deposit of water in the elastic tube, from condensation of the steam, has the effect of corroding the metal of the tube in course of time, producing material error in its rate of deflection, on account of the thinness of the metal; or is the cause of cracking the tube when the water becomes frozen by exposure to severe cold. The latter accident has occurred in many instances with gauges on fire engines and agricultural engines, which are liable to be placed in exposed situations; and to meet this difficulty the form of gauge shown in Figs. 2 and 3 is used, having a shorter spring-

tube A, in which there is not any receptacle for condensed water to collect. This shorter tube however has the disadvantage of shortening the range of spring action, requiring the motion to be multiplied to a correspondingly greater extent at the index, and consequently magnifying further any error in adjustment. The elastic tube is usually made of very thin brass, and sometimes of steel or platinum; but it is liable to become permanently strained by continued use, or by accidental exposure to a greater pressure than the limit within which it is intended to work safely; and the indications of the gauge are then no longer correct. Several modifications of this pressure gauge have been used, but they are still liable to the objections that apply to the principle of construction.

The Schaeffer gauge, shown in Figs. 5 and 6, Plate 81, has also been very extensively used for many years. The pressure is measured by the deflection of a circular steel plate B, shown full size in Figs. 7 and 8, which is 2 inches diameter in the opening, and is fixed round the circumference between the flanges of the casing, the steam being admitted to the underside. This plate is very thin and is formed with a series of concentric corrugations, which allow of its bulging under pressure; the underside of the plate is coated with some metal or composition not liable to be injuriously acted upon by steam or water. A short standard is soldered upon the centre of the upper side of the plate, and a connecting rod is jointed to it by a ball at its lower end, the other end being connected to a toothed sector which communicates rotary motion by a pinion to the index of the gauge; the connecting rod is made with a sliding joint fixed by a set screw, to adjust the toothed sector for gearing with the pinion. This gauge, though it has been considered one of the best in use, has a disadvantage in the very small range of deflection of the plate under the pressure, the range of motion amounting to only about 1-16th inch; and as this motion is magnified nearly 200 times in the indication upon the dial, any errors are also proportionately magnified. The plate is moreover liable to be permanently strained by an excess of pressure, and is also liable to crack when continually worked. The metal of the plate being very thin, its elasticity is liable to

be diminished when any oxidation takes place, and error in the indications is then the consequence.

In the Wallis gauge, shown in Fig. 9, Plate 82, the pressure is also measured by the bulging of a circular steel plate C, shown half size in Fig. 10, and full size in section in Fig. 11; but the range of deflection is increased by the plate being cut into six segments, by radial slits meeting in the centre, as shown in Fig. 10; the segments are only fixed at the circumference, and are free to move independently at the centre, instead of being rigidly combined in a single plate. The plate C is about $2\frac{1}{2}$ inches diameter in the portion exposed to the pressure, and is covered on the underside with a thin brass diaphragm or a sheet of vulcanised india-rubber D, Fig. 11, which is made tight round the circumference and serves to close all the radial slits in the steel plate, and prevent any passage of steam. A connecting rod jointed to one of the segments of the plate is connected at the other end to a toothed sector, which moves the index on the dial by a pinion. This gauge has the advantage of a greater range of action in the pressure plate than in the previous gauge, owing to the triangular segments being each free to deflect independently at the centre; but when the covering diaphragm D is made of brass it is found to be too rigid to admit of the requisite sensitiveness in the gauge; and when made of india-rubber, as is usually the case, it is liable to get forced by the pressure into the slits between the segments of the plate, causing them to be blocked open, and thus obstructing the action of the gauge.

The Miller gauge, shown in Figs. 12 and 13, Plate 83, is on another principle, having a solid piston E, about $1\frac{1}{4}$ inch diameter, which works in a cylinder and receives the pressure of the steam underneath, and is supported against the pressure by a curved steel spring fitted upon the top of the piston rod. The piston is made an easy fit in the cylinder, and is rendered steam-tight by a flat diaphragm of vulcanised india-rubber G, as shown full size in Fig. 14, which is secured round its circumference between the flanges of the cylinder. The face of the piston is ordinarily flush with the end of the cylinder, so that the india-rubber diaphragm is flat; and the range of motion of the piston is very small, only about 1-16th inch.

The rotation of the index on the dial is effected by means of a short watch-chain, coiled round a barrel upon the spindle of the index and attached to the two ends of a vibrating bow F, Fig. 12, which is actuated by a connecting rod from the piston rod; a small coiled spring is added round the spindle of the index, to ensure its coming back to zero when the pressure is taken off. This gauge has the disadvantage that the motion of the piston is limited to a very short range, owing to the risk of the india-rubber diaphragm getting cut round the edge of the piston with a longer action; and the construction of the multiplying gear for the index involves objectionable complication, and renders the gauge difficult to be repaired.

In the Smith gauge, shown in Figs. 15 and 16, Plate 84, which is on a different principle and has been extensively used, a steel volute spring H is employed, and is acted upon direct by the steam on one side, and has a considerable range of action compared with the gauges last noticed. The spring is $1\frac{1}{4}$ inch diameter, as shown full size in Figs. 17 and 18, and is supported in a recess round the circumference, being covered on the under face by an india-rubber diaphragm G, which is secured round its edge by the flanges of the casing and makes a steam-tight joint. When the spring is compressed by the steam admitted below, the india-rubber diaphragm follows it, fitting close to it in all positions, and preserves a steam-tight joint; the coils of the spring are sufficiently close together to support the diaphragm continuously. The face of the spring is a little convex when at rest, is about flat under the usual working pressure, and becomes concave under the full pressure. A connecting rod attached to the centre of the spring is formed at the top into a straight toothed rack, which gives rotary motion to the index of the dial by means of a pinion, and is guided by a grooved pulley opposite to the pinion. This gauge has proved one of the best in use, and is found to stand well; the spring is of a simple, strong, and durable construction, and free from risk of sensible alteration in its elasticity through oxidation or over-pressure, as it is of considerable thickness of metal, and capable of standing without permanent set a greater

deflection than that due to the highest pressure which it is intended to measure. An objectionable point in the gauge however is the employment of a rack and pinion for communicating the movement to the index, as the use of toothed gearing for this purpose, although adopted in most of the different constructions of pressure gauges, involves necessarily a chattering, however slight, between the teeth of the rack and pinion, which interferes with exactness in registering a reciprocating motion. The objection to spring indications for measuring variable pressures is the irregularity of their action, which gives an irregular oscillatory motion to the pointer; and these oscillations are increased by the intervention of a rack and pinion, on account of the play occurring in toothed gearing.

The Silvester gauge, shown in Figs. 19 and 20, Plate 85, is similar in principle to the last one, but has three concentric spiral springs K, placed one within another, and bearing at their upper ends in recesses in the casing, as shown full size in Fig. 21. The inner spring rests at the lower end upon the head of the centre rod L; the second spring rests upon a ring, which fits round the head of the centre rod and has a shoulder bearing upon it; and the outer spring rests upon a second ring, which fits round the first ring and bears similarly upon it with a shoulder. The under surface of these two rings and the head of the centre rod are covered by an india-rubber diaphragm G, $1\frac{1}{4}$ inch diameter in the effective opening; and the circumference of the diaphragm is secured by the flanges of the casing, as in the previous gauge, so as to form a steam-tight joint. When the steam pressure is admitted at the underside, the three spiral springs are compressed simultaneously, their range of action being limited by the rings at the base of the springs coming to a solid bearing upon one another. The motion is communicated to the index by a rack and pinion from the centre rod; consequently the same objection is involved as in the Smith gauge, of an inevitable chattering action between the teeth of the rack and pinion. There is also another objection in the practical difficulty of getting three separate springs to act correctly together, greater accuracy being required both in construction and repair than with a single spring.

The Foster gauge, shown in Figs. 22 and 23, Plate 86, is constructed on a similar principle of action; it has been designed to remedy the defects in the previous gauges, and has been found by the writer to be superior to the other gauges in use, with regard to durability, accuracy, and sensitiveness. The pressure is measured as before by the deflection of a steel volute spring H, $1\frac{1}{4}$ inch diameter, covered by an india-rubber diaphragm G, as shown full size in Figs. 24 and 25; but the movement of the spring is communicated to the index by a short rod, attached to the centre of the spring, which has a stud upon its outer end that works in a spiral longitudinal groove in the spindle J of the index. This groove makes about one revolution in the total range of the spring; and the driving stud is guided and held steady by passing through a straight slot in the fixed cylindrical casing within which the spindle J of the index revolves. A compact portable form of the gauge is shown in Figs. 26 and 27, Plate 87, in which the index spindle with the spiral groove works within a tube in the centre of the spring, the stud being fixed upon the inside of this tube. The strength of spring employed is proportionate to the limit of pressure to be measured, the total range of deflection being the same in each case, namely about $\frac{1}{4}$ inch, and the diameter of the spring the same. The deflection of the spring is magnified about 60 times by the motion of the index upon the dial, instead of nearly 200 times as in gauges upon other principles of action and having dials of the same size. This gauge is very simple in construction, and free from liability to get out of order, either by the spring getting strained or by wear in the moving parts; and it is found to be very sensitive in indicating small variations of pressure.

With all spring pressure-gauges it is advisable to have a syphon pipe in the connection to the gauge, as shown in Figs. 28 and 29, Plate 87, and not to allow the steam to act directly upon the gauge; but it is not necessary to fill the syphon pipe previously with water, as the condensation of steam in the exposed pipe supplies a sufficient quantity of water for keeping the syphon always charged.

In conclusion it may be remarked that the points to be aimed at in a satisfactory pressure gauge are:—

1. Freedom from risk of permanent strain of the spring by any extent of over-pressure to which it is liable to be exposed in the course of work; as any permanent set would cause error in the indications of the gauge.

2. Considerable thickness of metal in the spring, so that its elasticity may not be sensibly affected by any corrosion to which it can be exposed, and that it may not be liable to failure by fracture.

3. Long range of action of the spring in measuring the pressure, so as to reduce the extent to which any errors are multiplied by the motion of the index upon the dial.

4. Sensitiveness of the gauge to small variations of pressure at all parts of its range.

Mr. Ernest Spon exhibited specimens of several of the different gauges described in the paper, and showed some of them in action by means of a force pump, to show the return of the index correctly to zero on removing the pressure, without any permanent set being produced in the spring of the gauge. The Foster gauge, he remarked, was not injured in the slightest degree by being kept under the full pressure for a long period, but many gauges were liable to be permanently strained in that way; and in the Bourdon gauges the curved elastic tube was so delicate that he had known instances of these gauges getting strained, and thereby completely spoiled. He showed a specimen of a Foster gauge small enough to be carried conveniently in the pocket, and constructed specially with a view to boiler inspections, in order to afford a ready means of obtaining an independent and accurate indication of the pressure of steam in any boiler, instead of having to rely upon the gauge fixed on the boiler, which might be more or less inaccurate. The Foster gauge he believed was the only construction of pressure gauge that admitted

of being made of such a small size as the specimen exhibited for indicating pressures as high as 400 or 500 lbs., the whole being in a case only 2 inches diameter; smaller gauges of other constructions had indeed been made, but had been limited to very low pressures, not exceeding 30 or 40 lbs.

Mr. E. B. Marten observed that the subject of steam pressure gauges was very important to all employers of steam power, and it had almost invariably been his experience that after a few months' work the pressure gauges hitherto in use became defective. On testing them, they were hardly ever found correct throughout the whole extent of their range; and after boiler explosions he had often found that the pressure gauge which had been in use showed much less pressure than the boiler had really been carrying: in one instance only half the pressure was shown. He had used most of the gauges described in the paper, and had also small gauges of the same construction to carry about for testing boilers. Almost all of these however had been found to become more or less incorrect after frequent use; and he had consequently adopted in preference an ordinary indicator barrel, provided with four separate springs to give the required extent of range, and marked with very finely divided scales on the sides of the piston-rod guide. The indication was easily read off by the position of the flat top of the piston rod, very minute changes being ascertained with a magnifying glass; and he considered it preferable to trust to the accuracy of reading in this way, rather than to employ any gearing for magnifying the indication. The free action of the springs could readily be tried by hand at any time, so as to feel that they were working easily without sticking. In pressure gauges generally he thought it was a mistake to make the dials and hands so large as was often the case, because the risk of injury and inaccuracy was then very much increased.

The President enquired how many of the Foster gauges were now in use.

Mr. Ernest Spon said this gauge had only been about two years in use and there were now about 150 at work, the greater portion of which had been sent abroad. One had been in use for the

last nine months upon a locomotive on the Midland Railway working at a pressure of from 80 to 140 lbs.; it had been found very sensitive and had proved very satisfactory. There had been generally a prejudice against spring pressure-gauges and against the use of an india-rubber diaphragm; but Smith's pressure gauge, in which the spring and diaphragm were similar to those adopted in Foster's, had been successfully in use for upwards of ten years, and he had known instances of the india-rubber diaphragm standing satisfactorily for that length of time. Five years he believed was the time that the diaphragm was expected to stand without requiring renewal; and in one of these gauges which he had seen opened after seven years' use, the diaphragm continued so thoroughly sound, that the gauge after being repainted was sent out again as new. In the Foster gauge the india-rubber diaphragm was made nearly double the thickness, in proportion to its diameter; and he considered therefore it might safely be relied upon to be very durable. In the early gauges the spring had been made of the same thickness throughout; but an improvement had now been made by tapering the spring in thickness towards each end, so as to have the greatest thickness in the middle of its length, which had been found to render it considerably more sensitive. An important difference between the Bourdon gauge and spring pressure-gauges was, that if the former got injured it could not be repaired, but a new tube was required, and the dial had to be entirely graduated afresh; whereas a spring gauge could readily be repaired in a very short time, even though it might have been considerably strained. Having extensively exported pressure gauges to foreign countries, his attention had been drawn to the subject of their different constructions by the return of various gauges which had proved defective; and he had found the Foster gauge the most likely to obviate completely the objections that had been experienced with previous gauges.

Mr. T. Hawksley remarked that, with respect to the use of gauges under exceptionally high pressures for hydraulic purposes, amounting sometimes to 1000 lbs. per square inch or more, and also gauges applied to pumping engines for the purpose of exhibiting the

shocks occurring in pumping to a very considerable height, his own experience was not favourable either to the diaphragm gauges or to those constructed with a curved elastic tube on the principle of the Bourdon gauge. In either construction, when the pressure was either very high or came upon the gauge suddenly, he had found the plate or the curved tube soon changed its elasticity, and after a little use the gauge ceased to be capable of indicating correctly. So much difficulty had been met with in employing these gauges for such purposes that in some cases he had reverted to the old plan of an air gauge, in which a column of air in a glass tube was compressed by a liquid subjected to the pressure to be measured. Provided that care was taken to employ a liquid which did not absorb any air under pressure, and also that there were no sudden changes of temperature of considerable extent, such a gauge was very accurate and might be depended upon for showing the pressure with sufficient correctness. The great impediment of course to an air gauge was the change of temperature and consequent change of relative volume by the liberation or absorption of heat in the compression or expansion of the air; but the error arising from this cause might be allowed for, and thus by repeated observations sufficiently accurate results could be obtained. There was certainly considerable difficulty in originally graduating such a gauge, on account of the spaces in the scale becoming so greatly diminished at the higher pressures; but when the graduation had once been made, it continued correct ever afterwards.

The President remarked that, having had a considerable experience of various pressure gauges, and having used on locomotives a great number of the Smith gauges, in which the pressure was measured by the deflection of a volute spring, he was inclined to the conclusion that there was an advantage in that form of spring over any other which he had seen tried for pressure gauges. The volute spring was more massive, and was therefore relatively less affected by oxidation; and the extent of motion being greater, a smaller amount of multiplication by means of gearing was required. The india-rubber diaphragm he believed had never been a source of any difficulty, and had been found to last a very long time in working.

The mode of communicating the motion from the volute spring to the index in the Foster gauge, by means of the spiral groove cut in the spindle of the index, appeared to him to be open to objection, on account of the rubbing surfaces being so exceedingly small that the amount of backlash or wear after extended use would necessarily be considerable, and much greater he considered than in the rack and pinion of the Smith gauge, which, with the use of a light back-spring for holding the teeth of the pinion always in contact with those of the rack in the same direction, was a preferable arrangement. At a former meeting of the Institution he remembered a description had been given of a mode of actuating the index somewhat similar to that described in the paper, the spindle of the needle being made of a flat bar twisted spirally, which was moved by the forked arm of a lever, so that the longitudinal movement of the lever arm along the spindle was converted into a rotary movement of the spindle itself (see Proceedings Inst. M. E. 1855 page 129); that appeared to him a better arrangement than the spiral groove, as the rubbing surfaces were much larger and the wear would consequently be less. But he had found the rack and pinion a very good means of multiplying the deflection in a spring pressure-gauge, and experience showed there was very little objection to it. At the best however, metallic pressure gauges were imperfect instruments, and frequently to a great extent unreliable, and he concurred in considering the simple air gauge the most perfect; though it must be admitted that the metallic gauges were easy of application in a variety of cases where the air gauge could not be used, and with proper care in their construction and employment they could be made very useful in practice.

He proposed a vote of thanks to Mr. Spon for his paper, which was passed.

The adjourned discussion was then resumed on the paper read at a previous meeting "On the principal constructions of Breech-Loading Mechanism for Small Arms, and their relative mechanical advantages" (see Proceedings Inst. M. E. April 1871 page 92).

ON THE PRINCIPAL CONSTRUCTIONS OF BREECH-LOADING MECHANISM FOR SMALL ARMS, AND THEIR RELATIVE MECHANICAL ADVANTAGES.

By Mr. WILLIAM P. MARSHALL.

(*Adjourned Discussion.*)

Mr. A. Henry, of Edinburgh, whose rifle was one of those described in the paper, expressed (through the President) his regret at being unable to be present on this occasion, and wished to draw attention to the advantages of the principle of the vertical sliding block for closing the breech, which he considered the best mechanical arrangement, the force of the recoil being resisted by surfaces bearing at right angles to the line of strain. This mode of closing the breech allowed a straight passage into the cartridge chamber for loading, and also afforded an unobstructed view through the barrel to admit of inspection and cleaning. The mechanism by which the sliding breech-block was actuated was of very simple description, and the same lever that opened the breech also ejected the empty cartridge-case and cocked the hammer at the same time, allowing of great rapidity of firing. The hammer and the whole of the lock action were enclosed within the lock, and were thus completely protected from wet or dirt.

Mr. W. Soper, of Reading, pointed out that an important difference in his own from other rifles was that the breech lever was situated conveniently at the side of the lock, so as to be readily worked without shifting the hand from the trigger guard. Practically he had found this was a better position for the lever than any other, and it enabled the lever to be worked much more rapidly, so that as many as thirty rounds in a minute could easily be fired from the shoulder, taking aim, and in public trials as many as sixty rounds in a minute had been fired from a rest. To this advantage of rapidity of firing was also added another of the greatest importance, namely

perfect safety to the firer; for in the event of firing a defective cartridge, the breech-block effectually prevented any escape of gas backwards into the firer's face. With the Prussian needle-gun it was often necessary to fire from the hip, on account of the danger from the gas escaping backwards at the breech; and for arms of precision, to be fired from the shoulder, it was requisite that any escape of gas should be driven in the opposite direction, away from the firer's face, as was effected by the breech-block in his own rifle. There was also free access to the breech chamber of the rifle, so that the barrel could always be cleaned from the breech end, and a clear sight could be obtained through the barrel; in rifles that had to be cleaned from the muzzle it was found that after frequent cleaning the muzzle became so much worn that the accuracy of the shooting was interfered with; whereas the same amount of wear occurring at the breech end was of no consequence, and the rifle when cleaned entirely from the breech remained an effective gun for a much longer time. The action of the spring, hammer, and trigger, was exactly the same as in the Enfield rifle, and the hammer could be set at half cock or full cock in the same way. The striker was perfectly in line with the axis of the barrel, and the hammer struck its blow precisely in the same line. The extractor slide was worked entirely by the breech-lever, without any spring being employed to move it; and the power exerted at the first moment to start it was four times that applied to the lever, while at the end of its motion its speed was eight times that of the lever, by which means a very powerful and rapid extracting action was obtained. The breech-block working at right angles with the axis of the bore offered the most secure resistance to the strain of firing. The stock of the rifle was in one piece throughout its entire length, the lock-box being let into it. The number of separate parts in the lock and breech action was only twenty-three in all.

The President enquired how far this rifle would bear exposure to wet or dirt.

Mr. W. Soper replied that he had had one of these rifles placed under water for a fortnight, and then laid out in the open air for another fortnight, and at the end of the month it had been fired in

its dirty state, without being even wiped, and no mishap of any kind had occurred with it; it was fired just as rapidly as on any other occasion, without the slightest difficulty. It had also been publicly tried by pouring a quantity of sand into the breech-box, and then working the action backwards and forwards for several minutes, after which it was fired with perfect facility; in actual service however no rifle would ever be subjected to such rough usage. With regard to the soundness of the breech action, many of the rifles had been fired with as much as 210 grains of powder, when finished and in the stock, without sustaining any injury whatever in any instance; and as regarded the durability of the mechanism, many hundreds of rounds had been fired continuously without producing the slightest interference with the action.

The PRESIDENT remarked that the subject of the paper was not only one of particular interest in its mechanical aspect, but also one of national importance; and although he knew nothing of the different rifles described, except as regarded their mechanical construction, he should not hesitate to express his opinion upon some of the mechanical questions involved in the subject, feeling that it was one which called for the fullest discussion at the present time.

With regard to the use of a spiral spring in place of the ordinary flat mainspring, there appeared to be no reason why the spiral spring should not work well, when employed under suitable conditions; and he presumed it had been found from the experience of its working in the Prussian and Chassepot needle-guns that its performance was reasonably satisfactory. But the conditions of its use in these two guns were very different from those under which it had now been applied in the rifle selected as the national weapon for this country; in this case the spring was an exceedingly short one, and the strain upon it must necessarily be correspondingly great in order to do the required work; and moreover the spring itself was very difficult to be got at. On these accounts the rifle now selected appeared to him eminently unsatisfactory as a piece of mechanical construction. The great difficulty resulting from the use of this short spiral spring was that the pressure upon the trigger nose was so excessive as to render the pull-off impracticable without the aid

of some supplementary contrivance for relieving the pressure in the act of firing. Although the contrivance adopted for this purpose was exceedingly ingenious, it was at the same time in his opinion almost as unsatisfactory as the action of the spring itself. So much depended upon the original accurate fitting of the rubbing surfaces in this trigger action, and upon their state of cleanliness and degree of lubrication, that the pull-off must be very variable indeed, and calculated to mislead the person handling the rifle.

Another serious objection to the same rifle was that the breech-lever raising the breech-block had very small bearing surfaces against the block, and these bearing surfaces were very near the fulcrum of the block; there was therefore a comparatively heavy pressure upon them, which would increase their liability to wear, and under these circumstances he considered nothing but very superior workmanship and exceedingly hard bearing surfaces would secure a reasonably satisfactory action for any length of time. If the principle of the falling block was considered good enough to be adopted at all, it was at any rate carried out in a much more satisfactory manner in the Westley Richards rifle, which appeared to him to be exceedingly simple, and to possess several advantages in mechanical construction.

The rifle exhibited by Mr. Soper was certainly a most ingenious piece of mechanism, and in rapidity of firing it stood before all the other rifles. There appeared to be considerable force in the advantage attributed to this rifle, in respect to the security of the firer from escape of gas backwards; how far the objection of the gas blowing out backwards applied to the falling block of the Peabody rifle, which was really the origin of the Martini, he was unable to say; but it appeared to be effectually obviated in the Soper rifle by the employment of the transverse breech-block. Another advantage in this rifle was that the striking pin and the blow of the hammer were exactly in the direct line of the axis of the barrel. These were all excellent mechanical points, which would go far to secure the success of the rifle embodying them; and there were also points about nearly all of the rifles now exhibited which were exceedingly ingenious.

Reverting to the rifle which had been selected as the national weapon, he wished to take the opportunity of putting upon record his own opinion that it was not likely to give the satisfaction which was expected from it. This opinion was based upon purely mechanical considerations, and looking at the subject from that point of view he had no hesitation in saying that this construction of breech mechanism appeared to him to be most unsatisfactory, and not likely to answer well for any lengthened period of working.

The Meeting then terminated.
